PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Whooping Crane Riverine Roost Site Selection Update

Prepared by staff of the Executive Director's Office for the Governance Committee of the Platte River Recovery Implementation Program

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LIST OF ACRONYMS AND ABBREVIATIONS

AHR	Associated Habitat Reach
AL	Alfalfa
AMP	Adaptive Management Plan
AW	Agricultural Wetland
AWBP	Aransas–Wood Buffalo Population
BQ	Big Question
CDL	National Agricultural Statistics Service's Crop Data Layer
cfs	Cubic feet per second
CO	Corn
CWS	Canadian Wildlife Service
DE	Development
EBQ	Extension Big Question
EDO	Executive Director's Office
ft	Feet
GAM	Generalized Additive Model
GCV	Generalized Cross-Validation
GR	Grassland
HEC-RAS	Hydrologic Engineering Center's River Analysis System
ISAC	Independent Science Advisory Committee
LiDAR	Light Detection and Ranging
mi	Mile
MM	Meadow Marsh
NE	Nebraska
NF	Nearest Forest
NRCS	Natural Resource Conservation Service
NWI	National Wetland Inventory
OA	Other Agriculture
PRRIP	Platte River Recovery Implementation Program, or Program
PRRIP-AMP	Platte River Recovery Implementation Program Adaptive Management Plan
REML	Restricted Maximum Likelihood
RENEW	Recovery of Nationally Endangered Wildlife
RSF	Resource Selection Function
RSR	Relative Selection Ratio
SO	Soybeans
SRSR	Scaled Relative Selection Ratio
SSURGO	Soil Survey Geographic Database

SW	Sand and Water
TAC	Technical Advisory Committee
TCW	Total Channel Width
TL	Transmission Lines
UOCW	Unobstructed Channel Width
UFCW	Unforested Corridor Width
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WC-3	Whooping Crane Hypothesis #3

EXECUTIVE SUMMARY

E.1 Why are we performing an updated analysis of riverine roost site selection for whooping cranes?

The Platte River Recovery Implementation Program (PRRIP or Program) is charged with providing suitable whooping crane roosting habitat along the Program's Associated Habitat Reach (AHR) to contribute to the survival of whooping cranes during migration. Early in the First Increment of the Program, an emphasis was placed on learning more about the characteristics surrounding whooping crane roost sites to better inform Program land and water management. The Program's Adaptive Management Plan set out plans for testing hypotheses that whooping crane use was directly related to habitat suitability in the AHR (PRRIP 2021a, Whooping Crane Hypothesis #3 (WC-3)). Furthermore, First Increment Big Question #5 (PRRIP 2020; Page 22) directed Program science to identify important habitat characteristics for riverine roosting by whooping cranes.

To accomplish this, the Program systematically documented whooping crane roost locations in the AHR from spring 2001 – spring 2017. In a habitat selection analysis, characteristics of roost locations were compared to characteristics of nearby in-channel locations that were available but not selected by whooping cranes. Results of these analyses helped the Program to define suitable whooping crane roosting habitat and provided guidelines for land and water management (Howlin and Nasman 2017, PRRIP 2017b, Baasch et al. 2019a). Specifically, the Program has worked to create and maintain river channels with widths ≥650 ft that are unobstructed by tall, dense vegetation and cleared riparian forest along riverbanks and in-channel islands to create unforested corridor widths of ≥1,100 ft.

Since spring 2017, The Program has continued to monitor whooping crane roost locations and suitable habitat availability in the AHR. During fall 2017 – spring 2022 monitoring, the Program observed nearly as many roost locations (78 roosts; 207 total roosts) as were observed during the previous 17 years (85 roosts; 235 total roosts). Additionally, since 2015 a broader availability of unobstructed channel widths has been maintained within the AHR. With the additional roost locations observed in recent years, and under different available roosting conditions, a check in on the factors important for roost site selection is warranted. The objectives of this updated analysis are to:

1) provide additional information for defining suitable roosting habitat within the AHR;

2) inform the Extension Science Plan Big Questions 1-3, which ask how water and sediment augmentation can maintain suitable roosting habitat for whooping cranes (PRRIP 2022a);

3) inform Program land and water management to provide benefits for whooping cranes.

E.2 What are the potential policy implications?

Results of the updated analysis will guide Program management actions by either:

1) reinforcing the importance of current criteria established as suitable roosting habitat for whooping cranes. I.e., continue to manage land and water according to established criteria, or
2) identifying other factors to be included in the definition of suitable roosting habitat for whooping cranes. I.e., potentially adjust Program land and water management to improve habitat suitability.

E.3 How did we conduct the updated analysis?

To perform the updated analysis for selection of riverine roost sites, we systematically documented whooping crane roost locations in the AHR from spring 2001 – spring 2022. Next, the Executive Director's Office (EDO) and Technical Advisory Committee (TAC) identified habitat characteristics for selection of riverine roosts. The characteristics included were both manageable by the Program (e.g., unobstructed channel width) and unmanageable but important to consider for whooping cranes (e.g., human development). We then measured each characteristic at roosts and locations that were available but not used. Finally, the resource selection framework from prior analyses was used to test the importance of characteristics to predict selection of roost sites.

E.4 What did we discover about riverine roost site selection through the updated analysis?

- Whooping cranes selected roosts along river channels that:
  - were far from forests;
  - had wide unobstructed views;
  - were in areas with less human development.
- Roosting Conditions at Managed Areas
  - Unobstructed channel widths and distance to nearest forest were greater at roost locations managed by PRRIP and its partners. PRRIP's largest contribution was on the western half of the AHR where increased use of wider channel conditions (both UOCW and NF) mainly occurred on Program managed properties in 2015-2022.
- PRRIP contribution to whooping crane use of the central Platte River
  - The proportion of the whooping crane population using the AHR increased by 148% in areas after PRRIP management was implemented.

E.5 Do the results change the Program's criteria for highly suitable roosting habitat?

The Program's definition of highly suitable whooping crane roosting habitat has not changed because of the Program's five-year check-in on whooping crane roost site selection. Nearest forest and unobstructed channel width continue to be the most important factors influencing riverine roost site selection for whooping cranes. The Program will continue to manage for 1,100 ft of unforested corridor width, as the results from this updated analysis reinforced previous findings of whooping crane selection of roosts with a minimum distance of 550 ft from nearest forest. Due to the similarity of selection for unobstructed channel widths ≥650 ft, the TAC did not make a recommendation to change the Program's current criteria for highly suitable roosting habitat from the current unobstructed channel width of ≥650 ft.

Instead, the TAC asked the EDO to review the range of unobstructed channel widths at Program habitat complexes and identify locations where unobstructed widths are 1) narrower than can be maintained by river flow and 2) unobstructed channel width could potentially be increased through low-cost management actions like disking and/or spraying of banks to promote lateral erosion. The EDO and TAC evaluated all complexes and identified two (Cottonwood Ranch and Jerry F. Kenny Pawnee Complex) where unobstructed channel width should be increased. Moving forward, annual work plans for those complexes will include actions to promote widening.

The amount of development surrounding in-channel habitat was the only landscape-level factor found to influence riverine roost site selection. The amount of development surrounding on-channel habitat should also be considered when assessing habitat suitability for roosting.

1 - INTRODUCTION

The Platte River Recovery Implementation Program (PRRIP or Program) implements actions of the Whooping Crane (*Grus americana*) Recovery Plan (CWS and USFWS 2007) to reduce mortality during migration and protect migration stopover sites. More specifically, the Program manages water and land along the central Platte River in Nebraska to provide suitable whooping crane roosting habitat along the Program's Associated Habitat Reach (AHR). The Program's management objective for whooping cranes is to contribute to whooping crane survival during migration (PRRIP 2021a). To measure achievement toward this objective, performance indicators were developed and include:

- increase area of suitable roosting and foraging habitat;
- increase crane use days; and
- increase proportion of whooping crane population use.

Early in the First Increment of the Program, an emphasis was placed on learning more about the characteristics surrounding whooping crane roost sites to better inform Program land and water management. The Program's Adaptive Management Plan (PRRIP 2021a) included multiple hypotheses related to whooping crane habitat suitability and use of the Associated Habitat Reach (AHR) including the following priority hypothesis:

- WC-3 Whooping crane use is related to habitat suitability. Riverine habitat suitability for whooping cranes is a function of channel characteristics such as water depth, channel width, and unobstructed-view widths.

This hypothesis was prioritized and became the basis of a First Increment Big Question (PRRIP 2020) to link science learning to decision-making. The First Increment Big Question pertaining to suitable habitat for whooping cranes states:

- Big Question #5 (BQ #5) – Do whooping cranes select suitable riverine roosting habitat in proportions equal to its availability?

To answer BQ #5, the Program compared conditions (explanatory habitat variables) at riverine roost locations to nearby locations that were available, but not selected, for roosting. Howlin and Nasman (2017) tested both proportional landcovers (proportion of 3-mile area surrounding a use or available location covered by a specified landcover type) and point based variables (metrics measured from or at a use or available point location), as well as a limited set of management-based variables that included:

- *Unobstructed channel width* (UOCW) – width of channel unobstructed by tall, dense vegetation;
- *Total channel width* (TCW) – total width of channel from left bank to right bank, including vegetated islands;
- *Nearest forest* (NF) – distance to nearest riparian forest;
- *Unforested width* - width of channel unobstructed by riparian forest; and
- *Unit discharge* - total discharge (volume of water in cfs) divided by the wetted width of the active channel.

The analysis indicated that nearest forest and unobstructed channel width were the best predictors of roost site selection and proportional landcovers were not important to explain patterns of roosting.

Following this finding, the Program continued to systematically collect roost locations that were integrated into a refined analysis focusing on the previously identified management-based, in-channel variables (PRRIP 2017b, Baasch et al. 2019a). Both studies concluded nearest forest and unobstructed channel width were the most important variables to explain patterns of riverine roosting. Specifically, whooping cranes roosted disproportionately further from forest and in wider channels unobstructed by tall, dense vegetation than predicted by availability of those conditions. Using these results, the Program defined minimum criteria for suitable roosting habitat as river channels with *unobstructed channel widths* of ≥650 ft and an *unforested corridor width* of ≥1,100 ft (i.e., double the *nearest forest* suitable width of 550 ft to allow for 550 ft on either side of a roost within the channel).

The Program's Extension Science Plan specifies that roost site selection analyses be updated every five years (PRRIP 2022a) to reassess the minimum criteria for suitable roosting habitat. The Program now has five more years of information (fall 2017 – spring 2022) to add to the dataset used in Baasch et al. (2019a). This analysis will be used by stakeholders to:

1) provide additional information for defining suitable roosting habitat within the AHR;
2) inform Extension Science Plan Big Questions 1-3, which ask how water and sediment augmentation can maintain suitable roosting habitat for whooping cranes (PRRIP 2022a); and
3) inform Program land and water management to provide benefits for whooping cranes.

During the five additional years of data collection, in-channel conditions for roosting were stable throughout the AHR and were generally more suitable than most of the period of record (2001-2014). From 2015 – 2022, average UOCW remained near suitable (≥600 ft) throughout the reach in the main channel of the river (PRRIP 2022b, PRRIP 2023). We also observed multiple migration seasons with more roosts than typically observed during a migration season, including 51 roosts in spring 2018 and 22 roosts in fall 2021. Large numbers of roosts concurrent with increased availability of wider channels could reveal a selection of wider channels than previously available depending on the whether roosts are disproportionately located in wider channels than predicted by availability alone. Alternatively, a reevaluation under altered habitat conditions could reveal a change in the factors important for selection of roosts.

In the current analysis, we include all previously examined in-channel management-based variables except unit discharge. Unit discharge, calculated as discharge divided by wetted width, was initially intended to address uncertainty around how whooping cranes respond to river flow; serving as a proxy for water depth, something thought to be important in roost site selection. Following input from the Program's Independent Scientific Advisory Committee (ISAC) and Technical Advisory Committee (TAC), unit discharge was excluded from our updated analysis because of a temporal mismatch between flow at the time of selection on the evening prior to observing roost locations and flow at the time of observing roost sites the next morning. In addition, wetted width was derived from a hydrodynamic model with inputs from 2009 to inform channel geomorphology. Together these temporal mismatches in a highly dynamic sand bed river make results from this variable difficult to interpret.

We have also taken additional steps to broaden the explanatory variables considered in the current analysis of roost site selection. In addition to in-channel management-based variables, we included off-channel landcover as hypothesized to influence riverine roosting patterns. We incorporated the landcover product from Baasch et al. (2022) that builds on the Brei and Bishop

(2008) landcover classifications by defining finer-scale wetland features in the AHR. This product allowed us to generate landscape compositions that incorporated wetland features at a finer scale such as meadow marsh and agricultural wetland.

Finally, following ISAC guidance we have examined PRRIP's contribution to in-channel habitat metrics found to be important for whooping crane roost site selection. Specifically, we examine how unobstructed channel widths and distance to nearest forest have changed over time on managed and unmanaged properties across the AHR. Additionally, we evaluate how Program acquisition and/or management of properties within the AHR to provide suitable whooping crane roosting habitat has contributed to the proportion of the Aransas-Wood Buffalo whooping crane population roosting in the AHR.

Science learning objectives

Our Program science learning objectives were to:

- Identify in- and off-channel habitat characteristics associated with whooping crane riverine roost selection in the AHR.
- Understand the influence of landscape composition on whooping crane riverine roost selection in the AHR.
- Identify and quantify Program contributions to whooping crane roosting in the AHR.

Our results will provide information to help determine if the Program's definition of suitable roosting habitat needs to be updated and if there are changes to Program land and water management that might increase suitable roosting habitat to benefit whooping cranes during migration.

2 - METHODS

2.1 Study area

Our study area was the Program's AHR, encompassing a 90-mile reach of the central Platte River including a 3.5-mile buffer on either side of active river channels from US Highway 283/Interstate 80 junction near Lexington, Nebraska to Chapman, Nebraska (Figure 1). The AHR is characterized by river channels with associated wetlands, grassland, and forest in a landscape dominated by agriculture. The AHR is situated within the area of core use by whooping cranes migrating between Wood Buffalo National Park, Canada, and Aransas National Wildlife Refuge, Texas (Pearse et al. 2018). Observations of whooping cranes using the central Platte River prompted the AHR to become the only river segment in North America to be designated as critical habitat for migrating whooping cranes in 1979 (USFWS 1978). This critical habitat designation encouraged management efforts to widen river channels, rehabilitate wetlands, and remove woody vegetation in and near river channels to increase the availability of wide river channels and other habitats for whooping cranes.

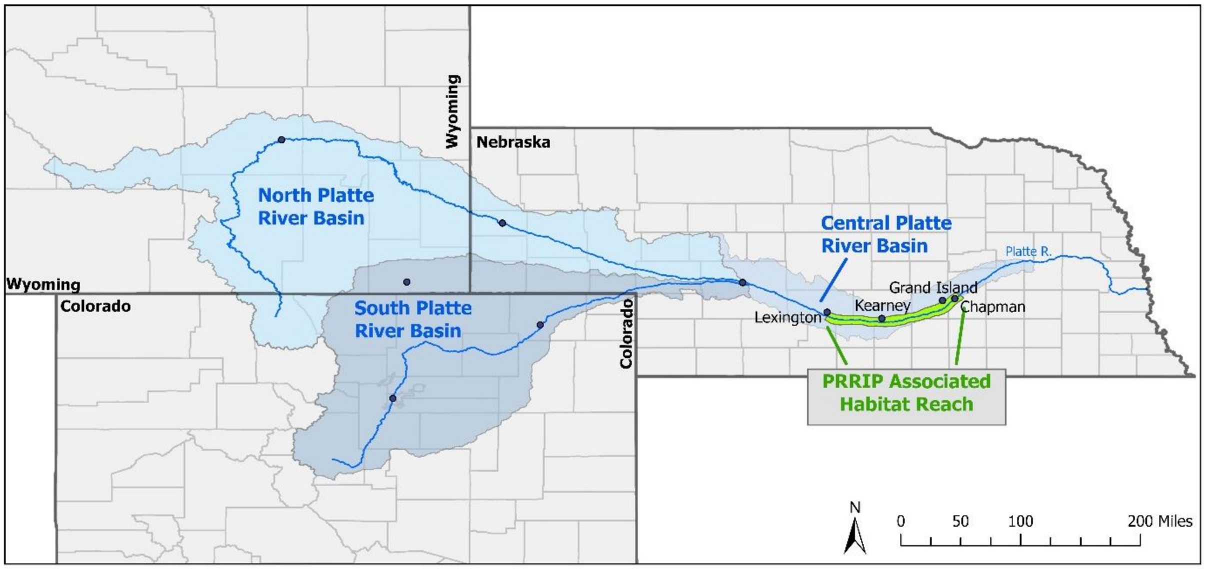

Figure 1. Map of the central and upper Platte River basin including the Program's Associated Habitat Reach (AHR) where management actions are implemented to benefit whooping cranes and other target species.

The central Platte River is a dynamic sandbed river system with a high degree of spatial and temporal variability in channel morphology and hydrology. Observations from the 19th and early 20th century described a wide and braided river with widths ranging from 1,500 to 4,000 ft until the 20th century. However, substantial narrowing occurred during the 20th century as water development intensified throughout the Platte River Basin (O'Brien and Currier 1987, Murphy et al. 2004). The primary driver of narrowing was reduction of flow due to water development, which encouraged woody (e.g. cottonwoods, willows) encroachment into the formerly active channel (Johnson 1994). The contemporary river consists of main and side channels with total widths ranging from approximately 400 ft to 1,500 ft (Fotherby 2009). Channel morphology, as distinguished by channel type, number of channels, and valley confinement, changes from the upstream to downstream ends of the AHR resulting in channel widths that are generally narrower upstream, widening as you move downstream (Fotherby 2009). Average unobstructed channel width, which is the linear distance unobstructed by tall, dense vegetation measured across the channel parallel to river flow, also varied over the course of our study period and influenced the amount of highly suitable in-channel habitat, as previously defined by the Program, available for roosting (PRRIP 2022b).

2.2 Roost and available location data

We identified whooping crane riverine roosts during spring and fall migrations per the Program's systematic whooping crane monitoring protocol (PRRIP 2017c) that relies on daily flights to locate crane groups while roosting on the channel prior to foraging in the adjacent landscape or leaving the area to continue migrating. We included the Program's systematic monitoring data from spring 2001 – spring 2017 published in Baasch et al. (2019a) and added roosts observed during systematic monitoring from fall 2017 – spring 2022. The Program's systematic monitoring protocol was first implemented in spring 2001. The monitoring protocol consisted of aerial surveys along established transects observing the main channel of the river, which was the widest channel of all channels with flowing water, during the first two daylight hours. Two aerial surveys were flown east to west each day with the east flight covering Chapman, Nebraska to the Highway 10/Platte River bridge near Kearney, Nebraska and the west flight covering Highway 10/Platte River bridge to Lexington, Nebraska. When a crane group was observed, photographs were taken that included in-channel features and the surrounding landscape to identify a roost location. The number and age category (i.e. adult or juvenile) of individuals in the group were also recorded.

Surveys of river channels remained similar from 2001 – 2022 except for the following changes in survey direction, return flights, and monitoring period.

- In fall 2001, spring 2002, and fall 2002 surveys of river channels were flown in the eastward and westward direction on alternating days (Platte River Endangered Species Partnership 2001*a*, 2001*b*, 2001c, 2002, 2003).
- Prior to fall 2013, daily return flights followed one of seven transects assigned randomly each day. Starting in fall 2013, return flights followed one of two transects to observe wetland complexes on routes that alternated every other day (PRRIP 2017*a*).
- The spring monitoring period spanned from March 21st to April 29th in 2001-2013 but was extended to March 6th starting in 2014 to continue monitoring between the 5th and 95th percentile of initial observations of whooping cranes in Nebraska during spring migration (PRRIP 2017*a*).
- The fall monitoring period spanned from October 9th to November 10th in 2001-2016 but was extended to November 15th starting in 2017 to continue monitoring between the 5th and 95th percentile of initial observations of whooping cranes in Nebraska during fall migration (PRRIP 2017*a*).
- Following the protocol, if the Program received information from the USFWS whooping crane tracking coordinator that a large proportion of the population had not yet migrated through the region or if whooping cranes remained within the AHR, surveys were extended past the established monitoring period.

The first observation of a crane group was considered the first, unique roost. Group demographics, roost location, and knowledge of other crane groups in the AHR on a given day were all used to identify each crane group. Along with the first unique roost, we observed subsequent daily roost locations to acquire the total roosts by each crane group during a stopover. We made a distinction between the first and subsequent roost observations of each crane group for analysis purposes because subsequent roost were not independent observations. Ignoring this lack of roost independence can lead to results that do not represent population-level selection but instead represent a small subset of longer stopovers that are overly represented in our dataset (Lennon 1999).

Our systematic monitoring identified 163 crane groups yielding 163 first, unique roosts (hereafter, roosts) from spring 2001 – spring 2022 (Figure 2). No surveys were conducted in the spring of 2003, so surveys occurred over a total of 42 migration seasons. More roosts were observed in spring 2018 (22 roosts) and spring 2022 (15 roosts) than any other season (Figure 2). The most roosts during fall migration occurred in 2019 (8 roosts). Of the 163 roosts, 85 were observed prior to fall 2017 and included in Baasch et al. (2019a). We observed 78 roosts from fall 2017 – spring 2022. The number of roosts averaged 3 per migration season prior to fall 2017 and 8 per migration season from fall 2017 – spring 2022.

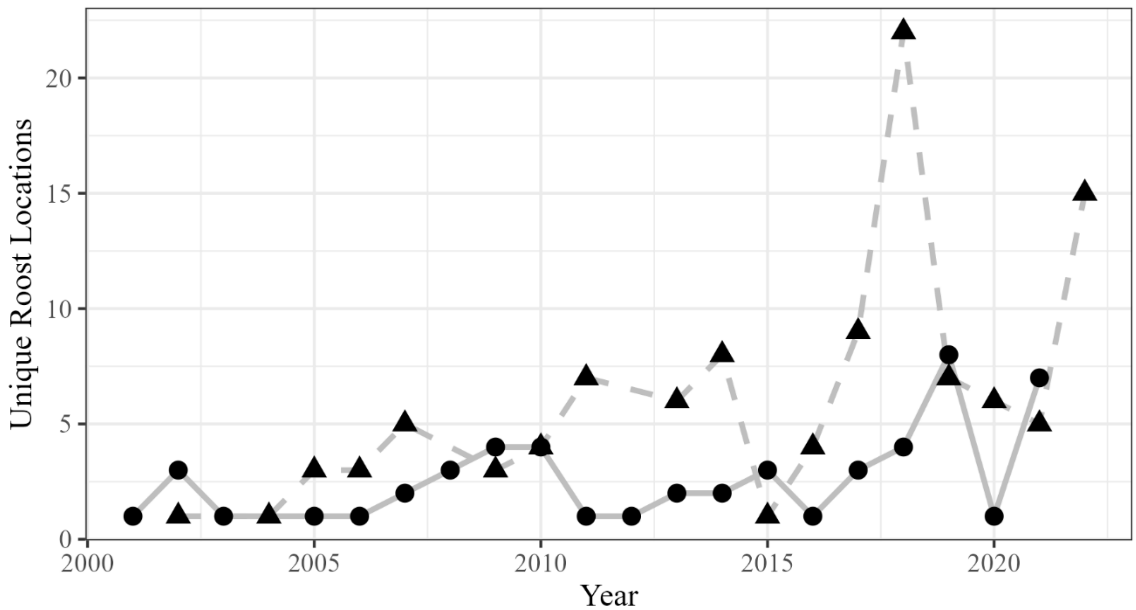

Figure 2. First, unique roosts (n=163) identified by systematic aerial monitoring within the Associated Habitat Reach during the spring (dashed line with triangles) and fall (solid line with circles) migration seasons from 2001 to 2022.

For each roost, we generated a set of 20 available non-selected locations (3,260 available locations) for comparison of habitat characteristics to the roost location. Available locations were generated at random within the active channels of the Platte River (including side channels) within 10 miles upstream or downstream of each roost location. Availability was limited to 10 miles from a roost site because cranes were likely unable to perceive roosting conditions at distances >10 miles when flying at 3000 ft above ground elevation, which was a common flight height between stopovers observed in multiple telemetry efforts (Kuyt 1992, Pearse et al. 2020). Furthermore, a Program analysis using whooping cranes carrying cellular transmitters (n = 32) found cranes deviated ≤8 miles from migratory flight path to stopovers along the Platte and Loup River systems from 2018-2021 (Whooping Crane Tracking Partnership, unpublished data).

2.3 Landcover products

We developed annual landcover products representing both in-channel conditions and the landscape surrounding active river channels (Appendix 1) from which to measure our explanatory variables. We start this process with the Brei and Bishop (2008) landcover that was created by the United States Fish and Wildlife Service (USFWS) - Rainwater Basin Joint Venture for the Program. This landcover compiled wetland information, Nebraska's Crop Data Layer (CDL; Boryan et al. 2011) from the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) for 2012, and field boundaries from the USDA Farm Service to map landcover across the AHR. To update this land cover with more detailed wetland information, we used the Brei and Bishop (2008) landcover with modifications developed by Baasch et al. (2022) that incorporate fine scale wetland features, as the foundational layer of landcover information for our study.

Since most of the landcover was based on information from 2005, we modified both in-channel and some aspects of off-channel landcover annually to better represent the conditions available to whooping cranes to roost within a given year. In-channel conditions from the 2005 land cover were replaced with object-based landcover classifications and spatial extent of river channel disking when necessary to represent annual conditions. For years prior to 2015, object-based classification was performed in eCognition (Trimble Geospatial, 2016. Version 9.3.1, Colorado, U.S.) using annual aerial imagery to identify water and sand within river channels. From 2015-2021, classifications were performed with LiDAR coverage, and allowed us to classify water, sand, and vegetation <2 ft, 2-6 ft, 6-15 ft, and >15 ft in height within river channels. In addition to object-based classifications, we also included the spatial extent of river channel disking within our study as disking occasionally occurred after imagery was acquired each year. Areas where disking took place were assumed to be sand and water for the fall in which they occurred and the spring of the following year.

Off-channel modifications of the 2005 base layer included both tree clearing and alternation among specific crop types. The Program and other conservation organizations have conducted large-scale removal of trees for whooping and sandhill crane habitat since Brei and Bishop (2008) was created. Tree clearings were defined as the removal of gallery forests consisting of mainly forests with cottonwoods (*Populus deltoides*) as the overstory layer were identified from the Program's land management geodatabase, as well as aerial imagery from 2005 to 2021. Tree clearings occurred within the floodplain where best available information was the static Baasch et al. (2022) layer. After updating this static layer by replacing areas of tree removal with grassland, we used aerial imagery to confirm the assumption of grassland structure moving forward through time, but no subsequent landcover products were available to provide a finer scale assessment. Off-channel annual landcover products mainly provided information on crop rotation within the AHR. We populated all upland agricultural areas, identified in Baasch et al. (2022), with annual crop type information from the National Agricultural Statistics Service's CDL (Boryan et al. 2011; Table 1). Whooping cranes have been observed more frequently in corn fields compared to other crop types (Howlin and Nasman 2017), suggesting increased corn near a roost location may be preferred. Alfalfa and soybeans may also be associated with whooping crane use during stopover activities (Caven et al. 2022). Since all the spatial data sources to develop these landscapes were created from annual fall conditions, each annual representation was used to derive explanatory variables in the fall of that year and the spring of the next year.

Table 1. Sources for landcover classifications used to quantify variables to explain roost selection of whooping cranes on the central Platte River from spring 2001- spring 2022. Similar landcover classes were grouped together to arrive at the more general landcover class represented by the explanatory variable. Landcover designations that correspond to one another across sources are contained within the same table row. See Appendix 1 for more information.

					Off-Channel Annual Adjustments	**In-Channel Annual Adjustments**
Abbreviation		**Explanatory variable**	**Brei and Bishop 2008**	**Baasch et al. 2022**	**Crop Data Layer**	**Object-Based Classification**
	SW	Sand and Water	River Channel Unvegetated Sandbar			Sand Water
	FO	Forest	Riparian Woodland Upland Woodland Rural Developed	Woodland	Forest	>15 ft vegetation height
MG	MM	Meadow Marsh	Floodplain Marsh Mesic Wet Meadow Basin Wetland Warmwater Slough	Meadow-Marsh		
MG	GR	Grassland	Meadow Sand Ridge Undisturbed Grassland Upland Grassland Xeric Wet Meadow	Prairie Wet Prairie	Grassland	
	AW	Agricultural Wetland	Agriculture + Palustrine Wetland	Agricultural Wetland		
	DE	Developed	Roads Urban/Suburban		Developed	
	CO	Agriculture + Corn (Corn)	Upland Agriculture	Agriculture	Corn	
	AL	Agriculture + Alfalfa (Alfalfa)	Upland Agriculture	Agriculture	Alfalfa	

SO	Agriculture + Soybeans (Soybeans)	Upland Agriculture	Agriculture	Soybeans
OA	Agriculture + Other (Other Ag)	Upland Agriculture	Agriculture	Other
	Other	Phragmites	Invasive Dominated Wetland	
		Purple Loosestrife		
	Other	Canal/Drainage	Open Water	
		Irrigation Reuse Pit		
		Lagoon		
		Reservoir		
		Sand Pit		
		Stock Pond		
	Other	Bare ground/Sparse Veg	Other	

2.4 Explanatory variables

We included explanatory variables hypothesized to explain patterns of roosting by whooping cranes. Channel openness is typically important for whooping crane riverine roost sites, especially in the AHR (Shenk and Armbruster 1986, Howlin and Nasman 2017, Baasch et al. 2019*a*) . We primarily used aerial and LiDAR imagery each fall along the entire AHR, along with a model built with the Hydrologic Engineering Center's River Analysis System (HEC-RAS; (Brunner 1996) to measure unobstructed channel width (UOCW) and total channel width (TCW). UOCW is the linear distance unobstructed by tall, dense vegetation measured at a roost or available point location in both directions across the channel perpendicular to river flow (Figure 3). From 2001 – 2016, UOCW was measured across river channels by hand delineation from aerial imagery taken during the fall season (Figure 3). Starting in fall 2017, we used object-based classification in eCognition to identify landcover from annual aerial imagery as water, sand, or vegetation (Table 1). The two methods were comparable in providing estimates of UOCW across years as demonstrated in comparisons from 2017-2020 (PRRIP 2022b). ECognition further classified vegetation in the active river channel into height classes of 0-2 ft, 2-6 ft, 6-15 ft, or >15 ft from annual topobathymetric LiDAR imagery (LiDAR). Water, sand, and the 0-2 ft vegetation height class were considered as unobstructed from a whooping crane's point of view. Areas with vegetation >2 ft in height were considered obstructed. In areas without full LiDAR coverage, we also considered river channel and unvegetated sandbars from the Brei and Bishop (2008) layer as unobstructed. To account for disking of the river channel to create bare unobstructed sandbars that occurred after the acquisition of aerial and LiDAR imagery in the fall, we layered the known extent of disking into annual landcover classifications and assumed areas disked within a year were sand for the fall migration of that year and spring migration of the next year. Remotely sensed landcover classifications allowed UOCW to be objectively measured across the channel without observer interpretation (PRRIP 2022b). To measure TCW, we developed a HEC-RAS model representing the floodplain of the central Platte River and used the topographical profile of river cross sections to calculate one-dimensional hydraulic outputs. Values for model roughness were derived from 2005 land use data from Brei and Bishop (2008). The model was calibrated using rating curves and LiDAR water surface elevations from March 2009, along with physically surveyed 2009 water surface elevations. We then identified the extent of active channel at each cross section from left to right bank from 2009 aerial imagery, across all active channels, to produce total channel width at the 5,000 cfs topographical profile (TCW). Thus, the TCW associated with each roost or available location was a one-time, 2009-based measurement of the total channel width at 5,000 cfs at the cross section nearest to the roost or available location.

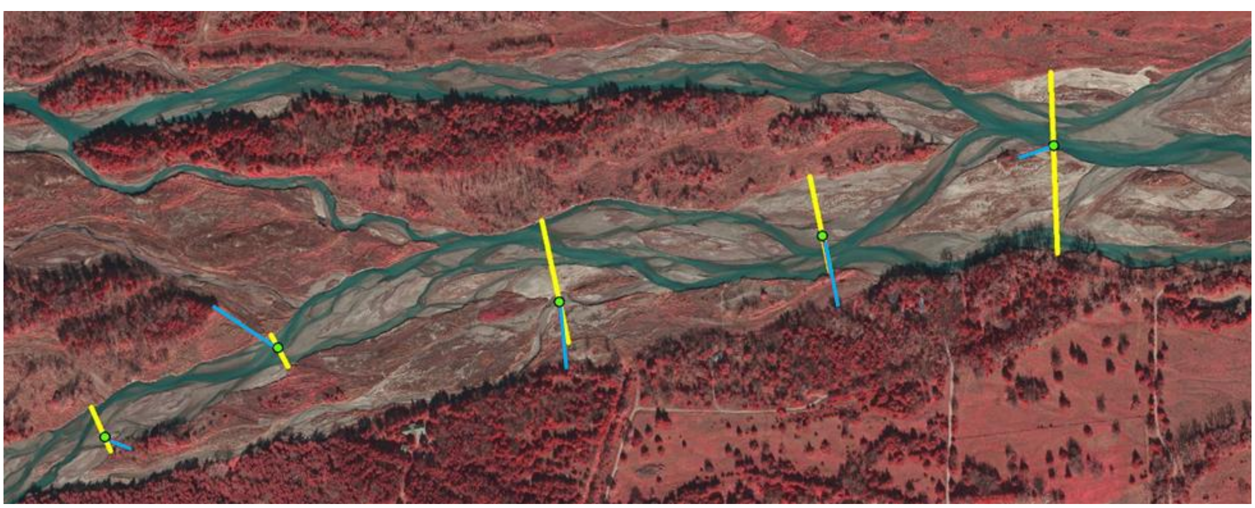

Figure 3. Example of how unobstructed channel width (UOCW; yellow lines) and nearest forest (NF; blue lines) were measured at whooping crane roost and available locations in the central Platte River from spring 2001 – spring 2022.

Whooping cranes generally avoid roosting near trees, thus forest is viewed as a having a negative impact on whooping crane roosting (Shenk and Armbruster 1986, Austin and Richert 2005, Pearse et al. 2017, Baasch et al. 2019*a*). To measure distance from roost and available point locations to nearest tree, group of trees, or forest in any direction (NF; Table 1), we relied on aerial and LiDAR imagery, supplemented with landcover classification and land management data. From 2001 – 2016, hand delineation was used to measure nearest forest from aerial imagery (Figure 3). We verified that hand-delineation and object-based classification methods produced comparable measurements of NF by measuring roost and available locations in fall 2017 and spring 2018 with both methods. With an average difference of 4% across methods, the Program's Technical Advisory Committee (TAC) deemed this was an acceptable amount of variability introduced by combining two methods for measuring NF over a long-term dataset with the added benefit of greater efficiency and repeatability, so object-based classification was used moving forward. Starting in 2017, we measured NF by combining the annual >15 ft vegetation class in the active channel with the riparian, upland woodland and rural development classes beyond the active channel from Brei and Bishop (2008), as well as forest identified in CDL data, to create an annual forest extent in the AHR (Figure 4). Rural development was included in the forest class because residential or commercial properties near the river were typically forested. Additionally, prior to measuring NF from 2017 – 2021, we updated each annual forest extent to reflect forest coverage changes not originally captured in Brei and Bishop (2008). We identified areas of tree removal, as well as the year removal occurred, and reclassified those areas as grasslands from that year until the end of our study. Measurements of

NF were capped at 1,312 ft to limit the influence of extreme values on predicted relationships of nearest forest to roost site selection (Baasch et al. 2019a).

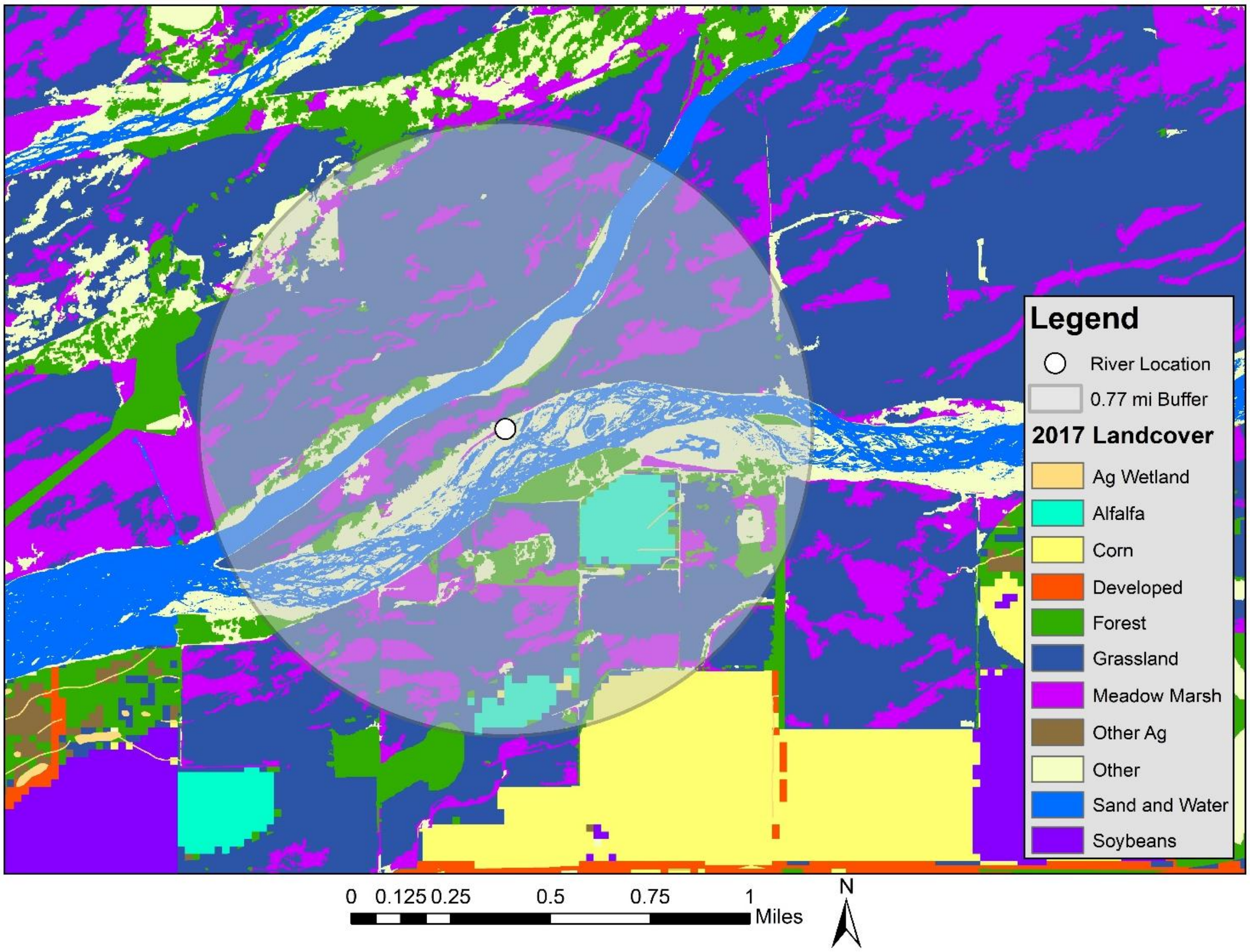

Figure 4. Example of the landscape used to quantify the proportion of each landcover class within 0.77 miles around each whooping crane roost and available location along the central Platte River from spring 2001 – spring 2022. Additional information in Appendix 1.

The surrounding landscape, providing foraging and resting opportunities, off-channel wetland features, or, alternatively, potential for disturbance was also hypothesized to influence whooping crane roosting patterns. We assessed the landscape composition within a 0.77 mi radius (buffer) around each roost and available location (Figure 4). We chose 0.77 mi because a Program analysis found 0.77 mi to be the radius of the average area used by whooping cranes carrying cellular telemetry units during stopovers along the central Platte and Loup Rivers (2018-2021; n = 50; Whooping Crane Tracking Partnership, unpublished data). Furthermore, recent publications have found similar landscape scales explain patterns of whooping crane use at stopovers (Pearse et al. 2017, Niemuth et al. 2018, Baasch et al. 2022).

As an in-channel aspect of landscape composition related to UOCW, a greater proportion of sand and water (SW) in the landscape was hypothesized to provide greater viewshed around a roost location (Shenk and Armbruster 1986, Pearse et al. 2017, Niemuth et al. 2018). We measured the proportion of SW within the 0.77 mi buffer around each roost and available location (Table 1; Figure 4). We used both the river channel and unvegetated sandbar classifications from Brei and Bishop (2008) and object-based classifications of sand and water. Prior to 2017, we used annual aerial imagery using object-based classification within eCognition that partitioned sand and water from vegetation. For the years when image quality was poor, we used a representative year of similar channel openness based on visual inspection of channel geomorphology from imagery. Specifically, we used 1998 imagery to classify SW for 2000-2002, Brei and Bishop (2008) classifications of river channel and unvegetated sandbar classifications for 2002-2006 SW, and 2010 imagery for 2007 – 2010. Starting in fall 2017, we identified SW from LiDAR-derived object-based classification. Like UOCW, we also accounted for disking that occurred after LiDAR was flown within a year and included disked areas in the quantification of quantify SW.

The composition of herbaceous wetlands and grasslands in the surrounding landscape were also hypothesized to be important predictors of whooping crane roost site selection. Whooping cranes have been observed selecting roost sites in or near herbaceous wetlands (meadow marsh), but selection of meadow marsh compared to other types of available grassland, both upland and lowland grasslands, has been less definitive (Niemuth et al. 2018, Baasch et al. 2019b). To test these hypotheses, we employed the Brei and Bishop (2008) landcover classification and the updated landcover classes from Baasch et al. (2022) to quantify the proportion of meadow marsh (MM), all grassland (MG), and agricultural wetland (AW) within the 0.77 mi buffer around roosts and available locations (Table 1; Figure 4). To create the meadow marsh class in Baasch et al. 2022, Brei and Bishop (2008) classifications were coupled with National Wetland Inventory Project (NWI; USFWS 2021) and flooding frequency information (USDA-NRCS 2019, 2020) to identify the most frequently flooded, herbaceous wetlands and sloughs along the central Platte River. Meadow marsh was combined with prairie and wet prairie classes (grasslands) from Baasch et al. (2022) to quantify all grassland (MG) representing the combination of wet and dry grasslands. Agricultural wetlands (AW) were palustrine wetlands, as indicated by the NWI, in agricultural fields of any crop type.

More development within the landscape and proximity to development have been negatively associated with use locations at stopovers during migration (Johns et al. 1997, Belaire et al. 2014, Pearse et al. 2021, Baasch et al. 2022). We also included development as an explanatory variable by measuring the proportion of development within 0.77 mi around each roost and available location. Development included roads and urban/suburban development from Brei and Bishop (2008), along with the development class identified from CDL data within upland agriculture areas (Table 1).

Agriculture fields consisting of corn were an abundant landcover type used by whooping cranes during diurnal activities in the AHR and the proximity to roost locations may be important (Howlin and Nasman 2017). We estimated the proportional area occupied by corn fields within the 0.77 mile buffer around roosts and available locations by using the CDL dataset within upland agriculture (Brei and Bishop 2008)/agriculture (Baasch et al. 2022) landcover types, which provided annual spatial information for agricultural products, including corn, in our study area from 2002-2021 (Han et al. 2012). No CDL data was available for 2000 and 2001, so we used CDL data from 2002 to approximate spatial coverage of corn from spring 2001 to spring 2002. We assumed spatial distribution of corn was similar 2000 – 2002 as 85% of the proportion of agriculture within our buffer for roosts and available locations was used for corn production across the study period. As such, it is unlikely major changes in corn distribution occurred between 2000 - 2002. Though proportional area covered by alfalfa, soybeans, or other agricultural products was quantified, specific hypotheses around the effect of these landcover types were not tested. All other landcovers types not previously mentioned were represented in the “other” category (Table 1).

We developed a list of twenty-eight *a priori*, hypothesis-driven candidate models that included our point-based in-channel or area-based landscape scale variables, as well as combinations of both, to explain roost site selection. For the current effort, we expanded the suite of in-channel models considered by Baasch et al. (2019a) by incorporating models including broader, off-channel landscape scale variables, as well as current and potential future options for management (Table 2). Additionally, we added models to explore interactions between UOCW and off-channel metrics of DE, CO, and MG to test whether the amount of disturbance, proportion of corn as a potential food resource, or proportion agriculture as a short, vertical vegetation structure off the river channel influenced the width of unobstructed views necessary for roosting. We did not include any explanatory variable combinations if the Pearson's correlation coefficient exceeded r = |0.6| (Figure 5). Prior to development of our suite of models, we chose among alternative metrics for representing the amount of agriculture, forest, and development on the landscape that were highly correlated by comparing their explanatory power to describe patterns of roost site selection for whooping cranes. Comparisons were made using the Akaike Information Criterion (AIC) scores of single variable models (Appendix 2). Candidate models were evaluated using an Akaike Information Criterion (AIC) selection process to identify the most powerful model(s) to explain roost selection while using the fewest explanatory variables (Burnham and Anderson 2002). As such, we identified the model used for inference(s) as the simplest, or most parsimonious model(s) with a ΔAIC $\leq$2.0.

Table 2. Suite of *a priori*, hypothesis driven models evaluated to explain roost selection of whooping cranes on the central Platte River from spring 2001- spring 2022.

Model[a]	Models	Interpretation
1	NULL	Habitat selection is random
2	Unobstructed Channel Width (UOCW)	Select wider channels with views unobstructed by dense vegetation or wooded islands.
3	Nearest Forest (NF)	Select channels without trees located nearby in any direction.
4	Total Channel Width (TCW)	Select channels with increased distance from right to left bank regardless of the presence of vegetated or wooded islands within the channel.
5	UOCW + NF	*Model used for inference from Baasch et al. (2019a):* Select channels with views unobstructed by dense vegetation without trees nearby in any direction.
6	UOCW + TCW	Select wide, open channels from right to left bank without dense vegetation obstructing views across the channel.
7	UOCW + NF + TCW	Select wide, open channels from right to left bank without dense vegetation obstructing views across the channel and trees nearby.
8	Sand and Water (SW)	Select for increased channel 'openness' (bare sand and water) within 0.77 mi

Model[a]	Models	Interpretation
9	All Grassland (MG)	Select for all grasslands (including meadow marsh) within 0.77 mi
10	Meadow Marsh (MM)	Select for lowland herbaceous wetlands within 0.77 mi
11	Agricultural Wetland (AW)	Select for lowland wetlands in agricultural fields within 0.77 mi
12	Development (DE)	Select against development within 0.77 mi
13	Corn (CO)	Select for upland corn within 0.77 mi
14	MM + AW	Select for any lowland herbaceous wetlands within 0.77 mi
15	AW+CO	Select for low lying, wet agriculture and upland cornfields within 0.77 mi
16	SW + MM	Select for channel openness and lowland, wet herbaceous vegetation within 0.77 mi
17	SW + MM + AW	Select for channel openness and all vegetated lowland wetlands within 0.77 mi
18	SW + AW + CO	Select for channel openness, lowland agriculture, and upland corn within 0.77 mi
19	UOCW + NF + MG	*Current Program management model:* Select for channels with unobstructed views, greater distances to nearest forest, with surrounding grasslands serving as buffer
20	UOCW + NF + MG + UOCW*MG	*Current Program management model* that also accounts for selection of wider unobstructed views as grasslands decrease within 0.77 mi
21	UOCW + NF + DE	*Model used for inference from Baasch et al. (2019a)* but also accounting for development within 0.77 mi
22	UOCW + NF + DE + UOCW*DE	*Model used for inference from Baasch et al. (2019a)* but also accounting for development within 0.77 mi and selection for wider unobstructed views as development increases within 0.77 mi
23	UOCW + NF + MM	*Potential future management model #1:* Current Program management model plus meadow marsh
24	UOCW + NF + MM + AW	*Potential future management model #2:* Current Program management model plus meadow marsh and agricultural wetland
25	UOCW + NF + MM + AW + CO	*Stakeholder model:* Program management model plus landcover variables hypothesized as important for roost site selection.

Model[a]	Models	Interpretation
26	UOCW + NF + MM + AW + CO + UOCW*CO	*Stakeholder model* but also accounts for a selection of narrower unobstructed views as corn increases within 0.77 mi
27	UOCW + NF + MM + AW + DE	*Potential future management model* but also accounts for the selection against increased development within 0.77 mi
28	UOCW + NF + MM + AW + DE + UOCW*DE	*Potential future management model* but also account for development within 0.77 mi and wider unobstructed views as development increases within 0.77 mi

[a]Models 2-7 include point-based, in-channel metrics from Baasch et al. (2019a). Models 8-18 identify the most important, literature supported, area-based metrics for whooping crane roost and diurnal resource selection. Models 19-28 combine on/off-channel metrics that reflect current Program management practices, variable combinations identified by Program stakeholders, and potential future management options.

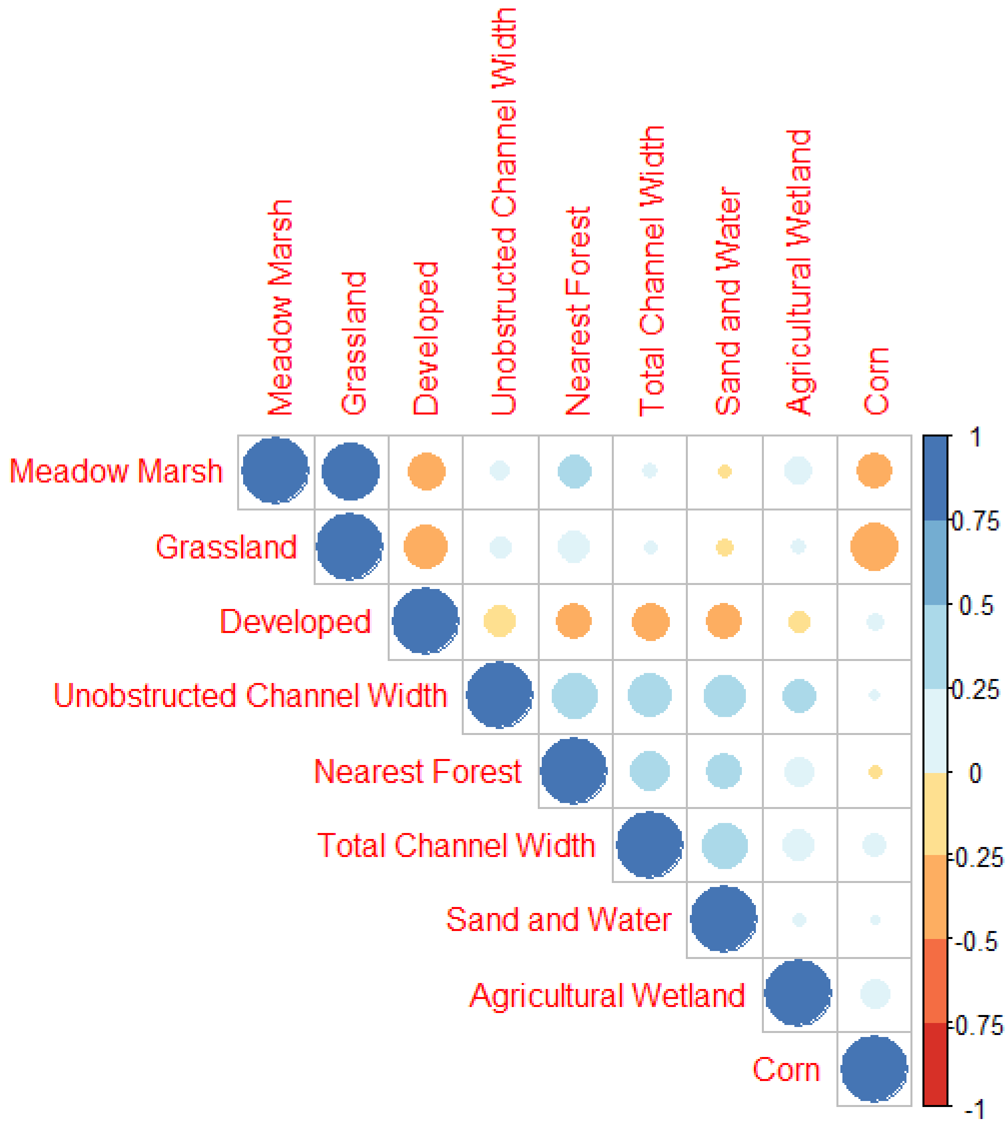

Figure 5. Correlation matrix of explanatory variables used to model resource selection of whooping cranes roosting along the central Platte River from spring 2001 – spring 2022. The degree and direction of correlation (correlation coefficient) between paired variables is indicated by the size and color of the symbol in the cell corresponding to the variables tested.

2.5 Roost site selection

In a sand bed river system with highly variable flow regime, channel morphology, and fluctuating land use practices, an analysis framework that pairs conditions at roost sites with conditions at nearby available sites at the time roost locations were observed allows for a fair comparison among selected and non-selected conditions. Our roost-available data collection allowed us to use resource selection functions (RSFs) with a discrete choice framework that accounted for changing availability of conditions during our study period (Johnson 1980, Arthur et al. 1996, McCracken et al. 1998, Manly et al. 2007). To account for possible non-linear relationships within RSFs, we used General Additive Models (GAMs) as an extension of the generalized linear model to estimate the relationship of selection and explanatory variables (Hastie and Tibshirani 1990). GAMs apply penalized regression splines, of smoothed terms, to allow for a variety of functional relationships, instead of relying on functional forms defined by investigators (Wood 2006). To limit overfitting and avoid results that may be ecologically irrelevant, we limited the potential degrees of freedom for smoothed terms to four. A smoothness value of 1 indicated a linear relationship and we removed the smoothing term for such variables and reran the candidate model. Our models evaluated a weighted relative selection ratio with a multinomial logit form expressed as:

$$w\left(X_{ij}\right) = \exp\left(s_1(X_{1ij}) + s_2(X_{2ij}) + \cdots + s_p(X_{pij})\right)$$

Where X_1 to X_p are metrics, j indexes the units in the choice set, and i indexes the unit selected, s_1 to s_p are used to smooth functions of X_1 to X_p, respectively. The discrete choice likelihood was maximized using R statistical software (R Core Team 2023) through RStudio (Posit Team 2023) with the gam function in R-package mgcv. We used a Cox Proportional Hazards Model with Restricted Maximum Likelihood within the gam function. The mgcv package determined the smoothness of the spline, and associated degrees of freedom, through iteratively re-weighted least squares fitting of the penalized likelihood (Wood 2006). The penalty for the smoothing parameters was determined at each iteration using generalized cross validation. Each candidate model was fitted with our GAM structure and then compared using our AIC model selection process.

Once model selection was complete, we examined the distributions and estimated relative selection ratios for each explanatory variable in the model used for inference. We initially compared the distribution of roosts and available locations across the range of habitat conditions by creating histograms demonstrating the percentage of locations within bins along the distribution of conditions for each explanatory variable. We then used relative selection ratios (RSRs), or relative probability of use, to estimate RSFs because availability was unique for each roost (Manly et al. 2007). We then predicted RSRs and 90% confidence intervals between the fifth and ninety-fifth percentile of each explanatory variable to avoid extreme predictions at the end of variable distributions. All other variables were held at their mean values when predictions were calculated. We then scaled each relative selection ratio by setting the maximum value of the 95th percentile to one, thus generating scaled relative selection ratio (SRSR) and 90% confidence intervals.

To evaluate differences in selection across UOCW measurements, we employed a bootstrapping approach. We generated 500 bootstrapped datasets by resampling with replacement from the original data. For each iteration, we applied the model used for inference to estimate SRSRs for UOCWs of 650, 700, 800, 900, 1000, 1100, and 1200 ft, as well as the maximized SRSR. We then calculated the difference between the maximized SRSR and each UOCW-specific SRSR. This produced a distribution of selection differences for each UOCW measurement. Following Efron (1979) and Efron and Tibshirani (1994), we assessed statistical significance using a one-tailed p-value, calculated as the proportion of bootstrapped differences less than zero. This tested the hypothesis that the selection at the maximized SRSR is significantly greater than selection at the UOCWs used for comparison.

2.6 Variable importance and model validation

We used a leave-one-out approach to estimate the importance of each variable for model fit, similar to variable importance procedures in random forest models (Breiman 2001) . Traditional effect sizes were not produced from smoothed functions, so we took each explanatory variable out of the model used for inference and reassessed model fit. We additionally removed UOCW and NF together to understand model fit when the most important explanatory variables from Baasch et al. (2019a) were missing from the model used for inference. Doing so produced a difference in deviance explained as variables were removed from the model used for inference. Deviance explained is a measure of model performance which describes how close the fitted model is to a "perfect" model. A deviance explained of 100% would be a "perfect" model composed of variables that together completely explain the difference between roost sites and available locations. Variables more important for explaining roost site selection exhibited larger reductions in the deviance explained upon their removal from the model.

We employed two different datasets to assess how well our model used for inference predicted observed roost locations in the AHR. The first dataset consisted of first, unique roosts observed from PRRIPs systematic aerial monitoring used in the analysis. The second dataset consisted of all roost locations obtained from telemetered whooping cranes collected outside of

PRRIP's systematic monitoring protocol. We used all roost locations from the telemetry dataset to have a greater sample size for validation (n = 74 roosts) and to test whether our model can sufficiently predict patterns of roost locations after the first roost location of a stopover. These data included AHR roost locations from GPS-marked whooping cranes from 2010-2016 (n = 29; Pearse et al. 2020b) and cellular-marked whooping cranes from 2018-2021 (n = 45 Whooping Crane Tracking Partnership, unpublished data). GPS terminals recorded locations every 4-6 hours, while cellular terminals recorded locations every 15 minutes. We categorized marked bird locations as ground points if the height above ground elevation was <33 ft and instantaneous speed was <22 mph, to account for device reading inaccuracies near ground level due to device specifications or GPS location error (Pearse et al. 2020a). Ground points were then grouped into distinct stopover events as defined in Pearse et al. (2015). To obtain roosts of marked birds within stopovers and to make those data comparable to observations from the systematic monitoring protocol, we identified and used the riverine location closest to 6:00 a.m. each day during a stopover event.

We minimized overlap between datasets that resulted from the collection of data simultaneously by two different methods and redundancy within the telemetry marked dataset using a buffer of 0.21 mi around each roost of a marked bird. A Program analysis found this buffer distance was the radius of the average area whooping cranes utilized within the active river channel during the first day of a stopover on the central Platte and Loup River systems from 2018-2021 (n = 50; Whooping Crane Tracking Partnership, unpublished data). Roosts recorded within <0.21 mi of one another on the same day may have been the same crane group recorded by both datasets. Moreover, multiple marked birds within <0.21 mi on the same day may have chosen roosts dependently as part of the same crane group. Given this rationale, we eliminated marked bird roosts if they occurred within 0.21 mi of a systematically observed crane group on the same day. If multiple marked birds roosted within 0.21 mi on the same day, only the roost of the adult bird with the most ground locations during the stopover was used. We also limited the number of roosts from any stopover event of marked birds to six to limit the influence of any individual stopover on model validation results. All stopover events of marked birds contained six or fewer roosts besides one stopover with twenty-three roost locations, from which we randomly chose six roosts.

To assess how well the model used for inference predicted observed roost locations in the AHR, we ran an iterative cross fold validation where 2/3 of first unique roosts trained parameters in the model used for inference and 1/3 tested the accuracy of predictions. This procedure was repeated 1,000 times with random samples of choice sets to populate the training and testing datasets. Second, we trained the model used for inference on the first unique roosts from systematic monitoring and then tested the predictive ability of the model on telemetry data collected outside of PRRIP's systematic monitoring protocol.

To test model performance, each validation dataset compared RSF scores of roosts in the testing dataset to categories of RSF scores (Boyce et al. 2002). We accomplished this by using the model used for inference to predict an RSF score for each training data point. We then identified 5^{th}-100^{th} percentiles of those scores in increments of 5%, to create twenty bins of percentiles and distributed each training data point into its appropriate bin based on an RSF score (Table 3).

Table 3. Model performance evaluation using telemetry data gathered outside of PRRIP's systematic monitoring protocol as the testing dataset. For evaluation of model performance with telemetry data, we compared the bolded columns with a simple linear regression.

Bin	Percentile	Sum of Relative Selection Scores	Training Data Roosts	Proportion of Expected Roosts	**Number of Expected Roosts**	**Testing Data Roosts**
1	0-5th	8.75	0	0.00	**0.00**	**0**
2	5th-10th	15.95	0	0.00	**0.00**	**0**
3	10th-15th	22.64	0	0.00	**0.00**	**0**
4	15th-20th	31.40	4	0.02	**1.82**	**0**
5	20th-25th	41.42	0	0.00	**0.00**	**0**
6	25th-30th	54.75	0	0.00	**0.00**	**1**
7	30th-35th	73.93	0	0.00	**0.00**	**2**
8	35th-40th	99.20	3	0.02	**1.36**	**1**
9	40th-45th	136.38	4	0.02	**1.82**	**0**
10	45th-50th	182.31	6	0.04	**2.72**	**0**
11	50th-55th	239.63	4	0.02	**1.82**	**2**
12	55th-60th	305.20	6	0.04	**2.72**	**2**
13	60th-65th	378.06	13	0.08	**5.90**	**1**
14	65th-70th	472.12	11	0.07	**4.99**	**8**
15	70th-75th	593.86	8	0.05	**3.63**	**6**
16	75th-80th	724.07	14	0.09	**6.36**	**9**
17	80th-85th	884.41	22	0.13	**9.99**	**10**
18	85th-90th	1069.91	19	0.12	**8.63**	**5**
19	90th-95th	1,343.33	20	0.12	**9.08**	**12**
20	95th-100th	1,910.87	29	0.18	**13.17**	**15**
Total		8,588.18	163	1	**74**	**74**

Once all points were distributed into their correct bins, we identified how many roost locations from the training data fell within each bin and divided the number in each bin by the total number of roost locations in the training data. This provided the proportion of roost locations expected to populate each percentile bin, which we then multiplied by the total number of roost locations in the testing dataset to obtain the expected number of roost locations. Our next step predicted RSF scores at roost locations in the testing dataset and distributed them into the appropriate bins. Doing so allowed us to compare the expected number of roosts to the observed number of roosts in each bin with a simple linear regression to assess the closeness of the slope to one (Howlin et al. 2003). For the cross validation, we averaged the slopes and confidence intervals from the total iterations of random sampling to grade model performance. A “good” predictive model had a 95% slope confidence interval incorporating one and excluding zero. An “adequate” predictive model had a 95% confidence interval of slope that did not incorporate one or zero and fit was “poor” if the 95% confidence interval of slope included zero.

2.7 Contribution of channel management to roosting conditions

It was also informative to compare roosting conditions used by cranes at managed and unmanaged river locations to understand how PRRIP and partner organizations have contributed to on-channel roosting habitat. Specifically, we examined how NF and UOCW at roost locations changed over time and with property management. For this effort we binned all first unique roost locations into whether they were managed by PRRIP, by partner organizations, or not managed to provide whooping crane habitat at the time of the observation based on property boundaries. However, if a property extended into the main river channel, where most management occurs for whooping cranes, we assumed that management influence extended across the full channel width. This assumption aligns with management practices and how unobstructed channel width (UOCW) and nearest forest (NF) are typically measured across the entire channel. In areas where PRRIP and other conservation groups had overlapping boundaries (e.g., Shoemaker Island Complex) in the main channel, we assigned management to PRRIP due to active channel interventions (e.g., disking, tree clearing) conducted by the Program. Each property, lease, or agreement was linked to the year it came under management by PRRIP starting in 2007 with the initiation of the Program’s First Increment or other conservation partners. To evaluate contributions by PRRIP and its partners in a way that isolated mechanical management efforts and their distribution over time and space from improvement in channel conditions resulting from base flows, we made these comparisons across three relevant time periods: 1) from 2001-2006, prior to any PRRIP acquisitions or management, 2) 2007-2014, following PRRIP land acquisition and management and under relatively stable hydrologic and geomorphic channel conditions, and 3) 2015-2022, further PRRIP acquisition and flood events in 2015 and 2019 that increased channel widths system-wide; Farnsworth et al. 2019, PRRIP 2022b). Secondly, we compared roost conditions separately in the western and eastern portions of the AHR due to differences in past conservation efforts, which were mostly concentrated east of Kearney, NE prior to PRRIP acquisitions.

2.8 PRRIP contribution to WC roosting

To understand if whooping crane use responded to channel management, we investigated whether whooping crane roosting on properties within the AHR increased after PRRIP began to manage them. To answer this question, we expanded our dataset to include all roost locations observed over the study. Each roost location was attributed to an identified crane group using the USFWS group identifier. For many groups, the number of individuals in the group changed as multiple roost locations were documented over time. In these cases, we used the maximum group size observed for each crane group. To get a before PRRIP management and following PRRIP management dataset for comparison, we limited our dataset to crane groups roosting in areas that earlier on were not managed by PRRIP but would eventually be managed by PRRIP.

Tracking temporal changes in PRRIP management

Areas managed by PRRIP were defined to include PRRIP-owned, easements, or agreement lands where PRRIP was responsible for maintaining or improving on-channel roosting conditions. Some properties were being managed by conservation and water user organizations to improve whooping crane roosting conditions prior to inception of the Program, while others were not. Migration seasons (both spring and fall) in the acquisition year and later were considered "after-PRRIP," while earlier seasons were "before-PRRIP." This classification allowed comparison of crane use per migration season before and after PRRIP acquisition of the same areas.

Standardizing crane use for population growth

Because the Aransas–Wood Buffalo Population (AWBP) almost tripled during the study period (from 176 cranes in winter 2001–02 to 543 cranes in winter 2021–22), a before and after comparison that did not consider the greater number of individuals could overstate PRRIP contributions over time. We therefore expressed each roost group, $g_{i,s}$, as a proportion of the contemporary population estimate, $N_{pop,s}$:

$$p_{i,s} = \frac{g_{i,s}}{N_{\text{pop},s}}$$

Winter estimates following the corresponding fall season and preceding the corresponding spring season were used for $N_{pop,s}$. For each migration season *s* within PRRIP-managed area *a*, the proportional use was calculated as:

$$U_{a,s} = \sum_{i \in A_{a,s}} p_{i,s}$$

where $A_{a,s}$ is the set of roost groups observed in area *a* during season *s*.

Aggregating and Season-Normalizing Area-Level Use

Season-level use was summed for each PRRIP area before and after acquisition:

$$U_{a,\text{before}} = \sum_{s \in S_{\text{before},a}} U_{a,s}, \qquad U_{a,\text{after}} = \sum_{s \in S_{\text{after},a}} U_{a,s},$$

where $S_{before,a}$ and $S_{after,a}$ are the sets of migration seasons experienced by area *a* before and after acquisition, respectively.

Because areas differed in the number of seasons they experienced, each cumulative total was divided by its season count to yield an average-per-season metric:

$$\tilde{U}_{a,\text{before}} = \frac{U_{a,\text{before}}}{|S_{\text{before},a}|}, \qquad \tilde{U}_{a,\text{after}} = \frac{U_{a,\text{after}}}{|S_{\text{after},a}|}$$

PRRIP Comparison Metric

The overall effect of PRRIP habitat management was expressed as an average percentage change across all PRRIP-managed areas per season:

$$\%\Delta U = \left[\frac{\sum_{a=1}^{A} \tilde{U}_{a,\text{after}} - \sum_{a=1}^{A} \tilde{U}_{a,\text{before}}}{\sum_{a=1}^{A} \tilde{U}_{a,\text{before}}} \right] \times 100$$

Positive values of $\%\Delta U$ indicate that, per migration season, PRRIP-managed areas collectively hosted a larger proportion of the AWBP after acquisition than before; negative values indicate the opposite. By standardizing each crane group to population size and normalizing for unequal numbers of migration seasons, the comparison formula isolates the effect of PRRIP management on roosting.

To statistically test whether whooping crane use increased following PRRIP acquisition, we compared the proportion of the population observed using a property per migration season before ($\tilde{U}_{a,\text{before}}$) and after ($\tilde{U}_{a,\text{after}}$) acquisition for each property. Because the before-and-after values represent repeated measures on the same properties, we used the Wilcoxon signed-rank test, a non-parametric test for paired data, to assess whether the median difference in proportion of population per season significantly changed following acquisition. Tests were first applied to all properties combined and then separately by the property's direction from Kearney, Nebraska (east vs. west half of the AHR), to examine whether spatial location influenced outcomes. Statistical analyses were conducted using R statistical software (R Core Team 2023) through RStudio (Posit Team 2023), and significance was assessed at $\alpha = 0.05$.

3 - RESULTS

Model Selection Results

The model used for inference (model 21 from Table 2) for predicting whooping crane roost locations included both in-channel variables and a single off-channel variable (Table 4). Models 27, 28, 22, and the selected model used for inference (model 21) all had a ΔAIC ≤ 2.0. However, the explanatory power gained by additional variables in models 27, 28, and 22 was not enough to overcome the penalty of including additional information, and model fit was very similar to model 21 (Arnold 2010). Additionally, selection relationships of UOCW, NF, and DE were similar in all the models with a ΔAIC ≤ 2.0, rendering the larger models as non-competitive (Burnham and Anderson 2002). Model 21 was selected for inference as it was the most parsimonious model with a ΔAIC ≤ 2.0.

Table 4. Top 5 models of roost selection by crane groups at stopover sites on the central Platte River from spring 2001 – spring 2022 as ranked by the Akaike Information Criterion (AIC) statistics. The AIC statistic of the null model was 2961. Variable descriptions are included in Table 1. The model used for inference (bold) was model 21, as it was the most parsimonious (or simplest) model with a ΔAIC ≤ 2.0.

Model	Variables	df	AIC	ΔAIC	Weight
27	NF + UOCW + MM + AW + DE	174.32	2784.93	0.00	0.28
28	NF + UOCW + MM + AW + DE + UOCW*DE	174.32	2784.93	0.00	0.28
22	NF + UOCW + DE + UOCW*DE	169.76	2785.19	0.26	0.25
21	**NF + UOCW + DE**	**170.02**	**2785.73**	**0.80**	**0.19**
24	NF + UOCW + MM + AW	173.56	2796.67	11.74	0.00

Variable Importance

NF and UOCW were the most important variables to explain roost site selection based on deviance explained (Table 5). The deviance explained decreased by 26% when NF and 16%

when UOCW were removed from the model used for inference individually. When NF and UOCW were removed together, the deviance explained decreased by 74%. The deviance explained decreased by 9% when development was left out and model fit was reassessed.

Table 5. The deviance explained (DV) by the top roost selection model compared to DV of models with explanatory variables withheld to assess variable importance to model fit.

Withheld Explanatory Variables	DV	Decrease in DV	% Decrease in DV
NF, UOCW	0.05	0.13	74
NF	0.13	0.05	26
UOCW	0.15	0.03	16
DE	0.17	0.02	9
None (Model used for inference = UOCW + NF + DE)	0.18	-	-

Nearest Forest (NF)

Whooping cranes typically roosted farther from forest than availability would predict, suggesting avoidance of proximity to forested areas. Distance to NF exhibited a positive trend up to the maximized distance of 623 ft, beyond which the probability of selection decreased (Figure 6). Roost locations were, on average, 433 ft from NF, whereas available locations averaged 255 ft from NF. The degrees of freedom for in-channel smoothed terms were 3.50 for NF ($p = <0.001$).

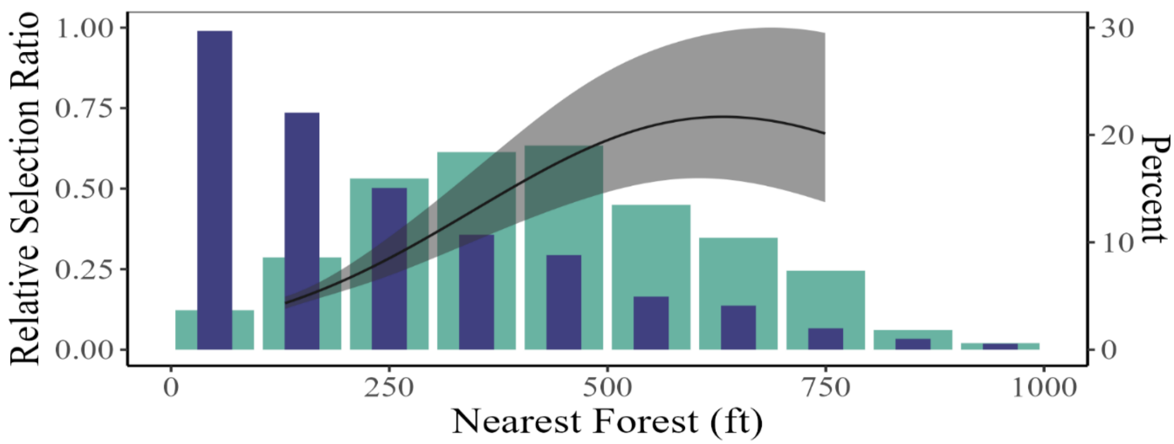

Figure 6. Relative selection ratio of Nearest forest for whooping crane roosts collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationships between the 5th and 95th percentile of each variable at roost locations, while the grey shaded areas represent the 90% confidence intervals. The green bars represent the percentage of roosts, whereas the blue bars represent the percentage of available locations across the range of nearest forest.

Unobstructed Channel Width (UOCW)

Whooping cranes also typically roosted in channels with wider, unobstructed views (25th percentile = 463 ft, median = 674 ft, 75th percentile = 935 ft) than availability might indicate (25th percentile = 111 ft, median = 323 ft, 75th percentile = 689 ft). Selection of UOCW exhibited a non-linear (degrees of freedom = 3.43, p = < 0.001) positive trend up to about 650 ft and then remained stable from 650 ft to the 95th percentile of UOCW at roost locations (1,223 ft; Figure 7).

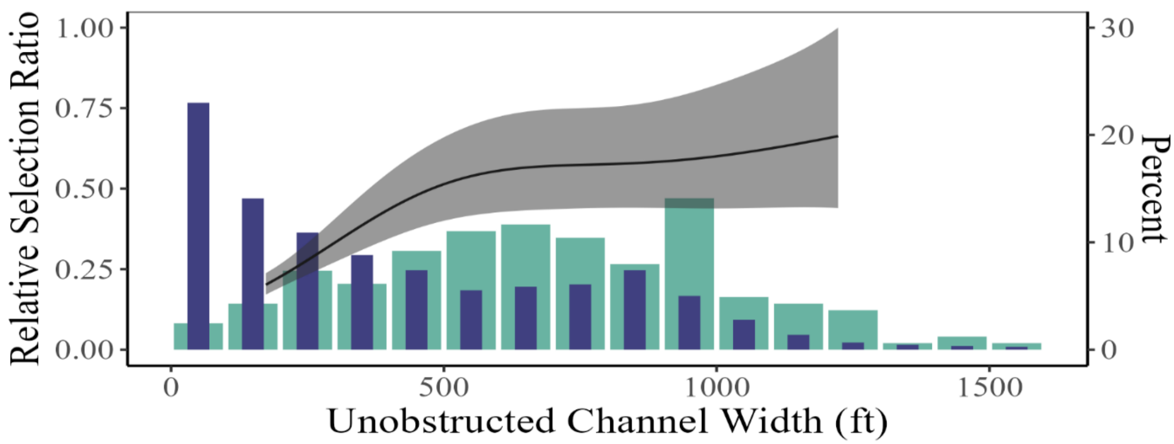

Figure 7. Relative selection ratio of Unobstructed Channel Width for whooping crane roosts collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationships between the 5th and 95th percentile of each variable at roost locations, while the gray shaded areas represent the 90% confidence intervals. The green bars represent the percentage of roosts, whereas the blue bars represent the percentage of available locations across the range of unobstructed channel width.

Selection of UOCW was maximized at 1,223 ft, but given the uncertainty of the estimate, selection at 1,223 ft was statistically similar to selection at widths of 650-1200 ft ($p \geq 0.99$). Similarly, all other comparisons of selection at UOCW from 700-1223 ft with selection at 650 ft were statistically similar ($p \geq 0.45$). Roost sites were distributed across a range of UOCWs, with 70.6% of roosts occurring at locations where channel widths were 900 ft or narrower, but with the highest number of roosts occurring in the 900–1000 ft bin (n = 23, 14.1% of all roosts; Figure 7 and Table 6). Beyond 1000 ft the number of roosts dropped off together with availability.

Table 6. Distribution of systematically collected first unique roost locations from spring 2001 – spring 2022 and corresponding available locations across unobstructed channel widths (bin width = 100 ft). Roost percentages were calculated by dividing the count of the number of roosts with unobstructed channel widths in a bin by the total number of first, unique roosts (n = 163). The same procedure was used to calculate available percentages, with counts of available locations in each bin divided by the total number of available locations (n = 3,257).

	Unobstructed Channel Width Range (ft)																
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	Total
Roosts	4	7	12	10	15	18	19	17	13	23	8	7	6	1	2	1	163
Percent of Roosts	2.5	4.3	7.4	6.1	9.2	11.0	11.7	10.4	8.0	14.1	4.9	4.3	3.7	0.6	1.2	0.6	100
Total Percent of Roosts	2.5	6.7	14.1	20.2	29.4	40.5	52.1	62.6	70.6	84.7	89.6	93.9	97.5	98.2	99.4	100.0	
Available Locations	749	459	355	287	241	180	191	198	241	163	91	45	22	15	11	9	3257
Percent of Available Locations	23.0	14.1	10.9	8.8	7.4	5.5	5.9	6.1	7.4	5.0	2.8	1.4	0.7	0.5	0.3	0.3	100
Total Percent of Available Locations	23	37.1	48	56.8	64.2	69.7	75.6	81.7	89.1	94.1	96.9	98.3	99	99.5	99.8	100	100
Ratio (Roost%/Available%)	0.1	0.3	0.7	0.7	1.2	2.0	2.0	1.7	1.1	2.8	1.8	3.1	5.4	1.3	3.6	2.2	

Development (DE)

DE was the only off-channel variable included in the model used for inference and the only off-channel variable to contribute explanatory power to patterns of roost selection (Table 4). Whooping cranes typically roosted in areas with less development within 0.77 mi than availability would indicate (Table 5, Figure 8). Selection of development exhibited a negative trend, where the maximized selection was at zero proportion of development within 0.77 mi. The degrees of freedom for development was 2.7 for DE (p = <0.001).

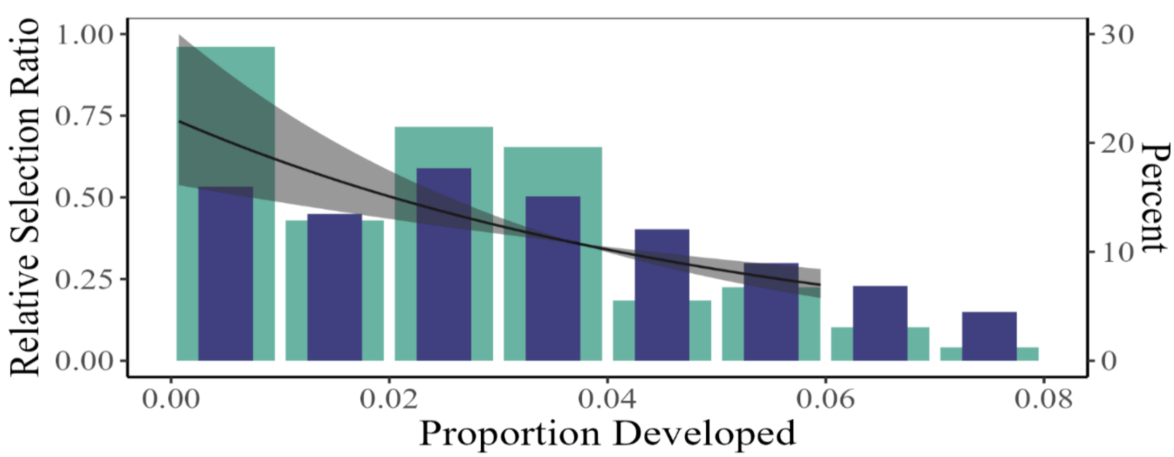

Figure 8. Relative selection ratio of proportion of development for whooping crane roosts collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationships between the 5^{th} and 95^{th} percentile of each variable at roost locations, while the gray shaded areas represent the 90% confidence intervals. The green bars represent the percentage of roosts, whereas the blue bars represent the percentage of available locations across the range of proportion of development.

Model Validation

Cross-validation using PRRIP's systematic monitoring dataset and validation using telemetry-marked birds both indicated good model fit of the model used for inference. The average slope and confidence interval was 0.64 (95% CI = 0.24 – 1.05) for cross-validation and 1.05 (95% CI = 0.78– 1.32) when using telemetry roost locations as the testing data.

Contribution of channel management to roosting conditions

Across the entire AHR, despite high variability in seasonal use during individual years (Figure 2), the proportion of population per season averaged 0.0152 in 2001-2006, 0.0349 in 2007-2014, to 0.0506 in 2015-2022. In the western AHR (Figures 9 - 10), the proportion of the population increased from 0.00290 per season during 2001–2006, to 0.00436 in 2007-2014, to 0.0132 per season during 2015–2022. In the eastern AHR (Figure 9 – 10), the proportion of the population per season increased from 0.0123 in 2001 – 2006, to 0.0305 in 2007-2014, to 0.0374 in 2015-2022.

Increased use by whooping cranes was associated with wider unobstructed channel widths (UOCW), particularly at roosts within managed areas. Throughout the AHR, UOCW at roosts increased from a median of 443 ft in 2001-2006, to 585 ft in 2007-2014, and 822 ft in 2015-2022. In the western AHR, UOCW at roosts increased from a median of 293 ft in 2001-2006, to 359 ft in 2007-2014, and 764 ft in 2015-2022 (Figure 8). In the eastern AHR, UOCW at roosts increased from a median of 449 ft in 2001-2006, to 622 ft in 2007-2014, and 845 ft in 2015-2022 (Figure 9). By 2015–2022, UOCW at roosts in managed areas was wider than in unmanaged areas across both the western (median of 827 ft vs. 522 ft; Figure 8, bottom left) and eastern AHR (median of 866 ft vs. 845 ft; Figure 8, bottom right), with the difference more pronounced in the west.

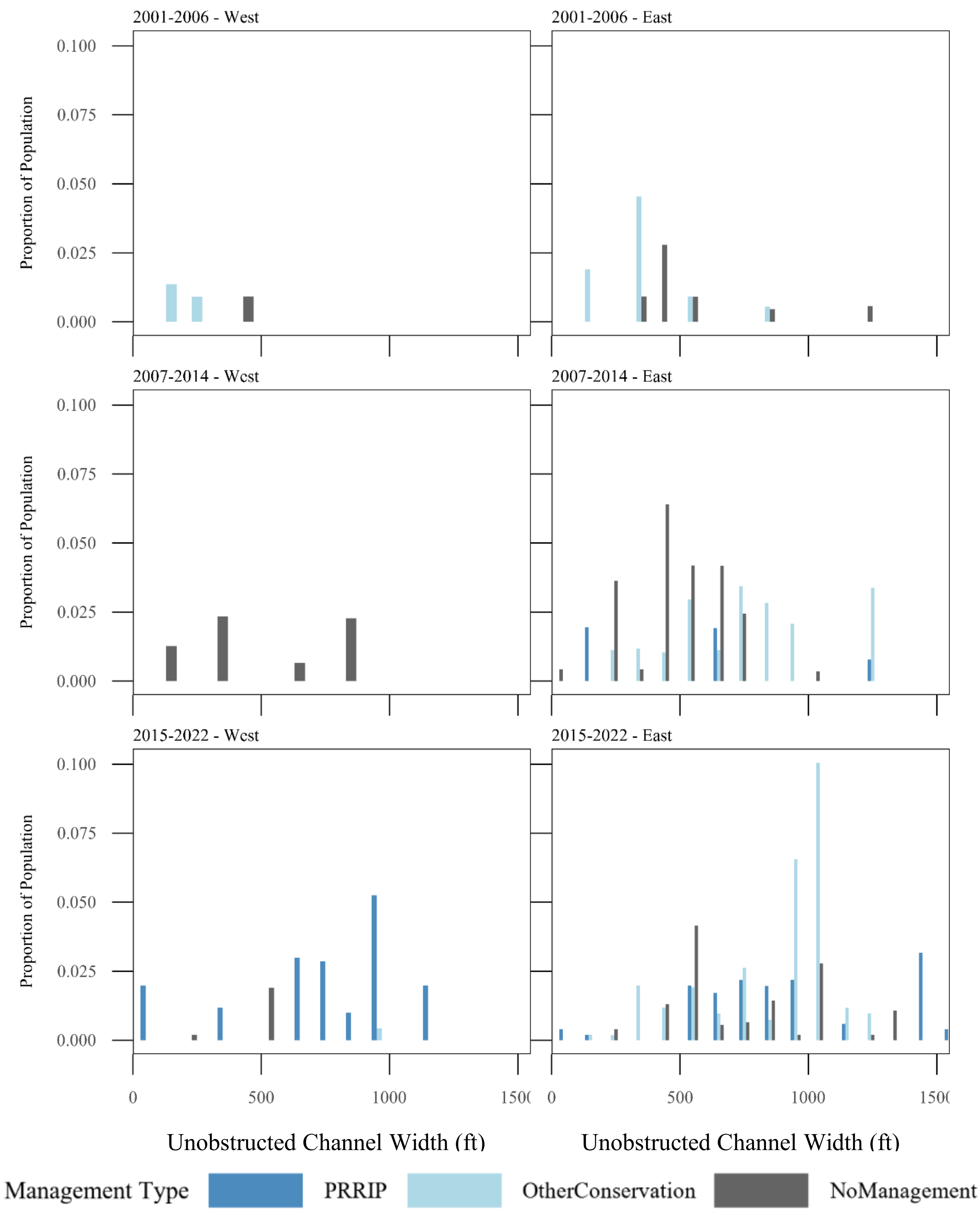

Figure 9. Distribution of whooping crane roosting across unobstructed channel width (UOCW) in the western AHR (west of Kearney) and eastern AHR (east of Kearney) by management type during three time periods (2001–2006, 2007–2014, 2015–2022). Bars represent the proportion of the Aransas–Wood Buffalo Population using each bin of habitat conditions during each period.

Changes in NF over time were less consistent than UOCW, but by the end of the study period the distance to nearest forest at roosts was greater in managed areas compared to unmanaged areas. The median NF at roosts was 414 ft from 2001-2006, 371 ft in 2007-2014, and 438 ft in 2015-2022. In the eastern AHR, median distance to NF changed little over time, whereas NF varied in the western AHR (Figure 10). The median NF at roosts in the eastern AHR was 445 ft from 2001-2006, 412 ft in 2007-2014, and 476 ft in 2015-2022 and 406 ft, 204 ft, and 325 ft during the same time periods in the western AHR respectively. By 2015 – 2022, the median distance to NF at roosts in managed areas was 335 ft compared to only 221 ft in unmanaged areas in the western AHR (Figure 10, bottom left). Similarly, the median distance to NF at roosts in managed areas was 492 ft compared to only 340 ft in unmanaged areas in the eastern AHR (Figure 10, bottom right).

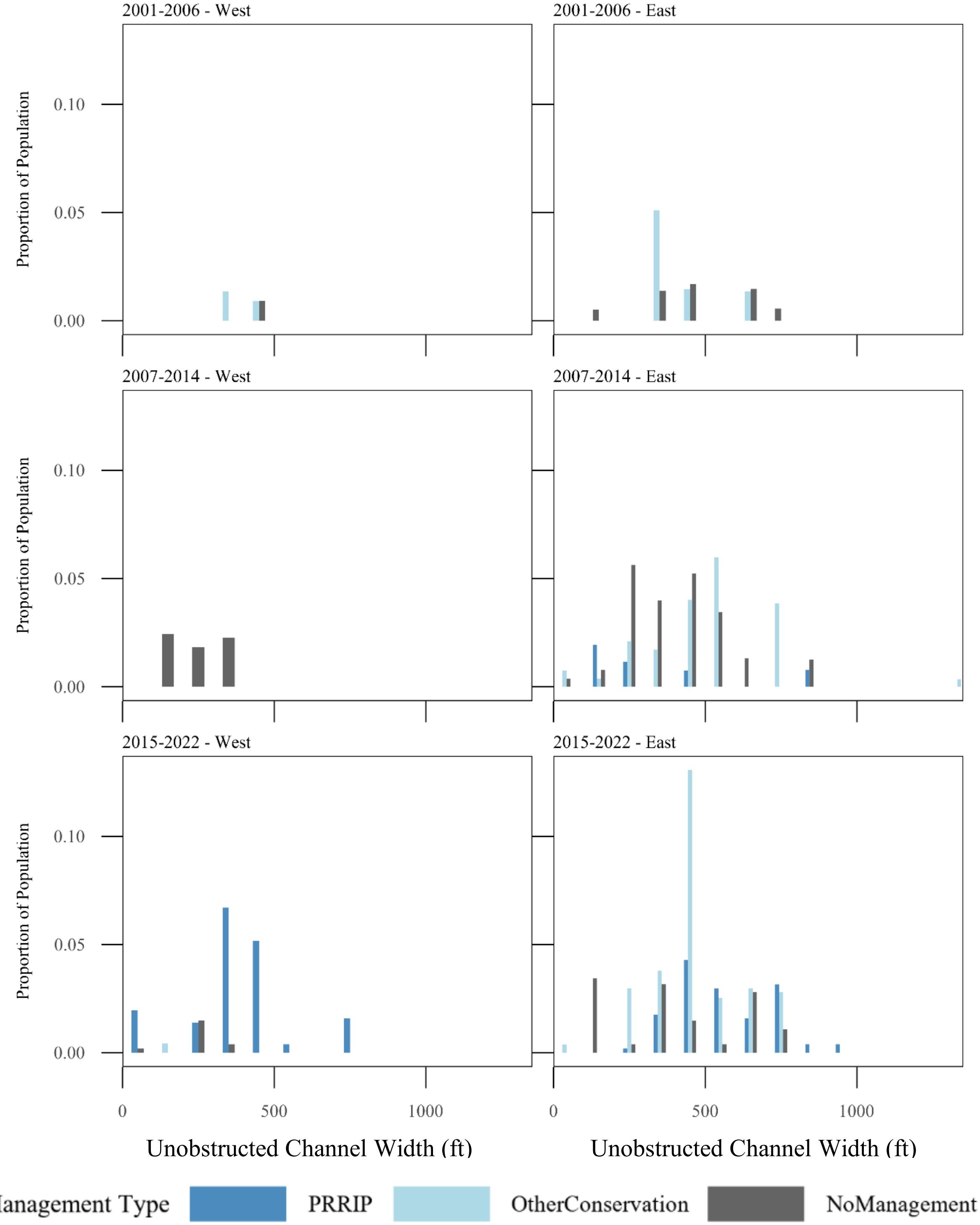

Figure 10. Distribution of whooping crane roosting across distances to nearest forest (NF) in the western AHR (west of Kearney) and eastern AHR (east of Kearney) by management type during three time periods (2001–2006, 2007–2014, 2015–2022). Bars represent the proportion of the Aransas–Wood Buffalo Population using each bin of habitat conditions during each period.

PRRIP contribution to WC roosting

Across all PRRIP managed areas, the proportion of the population roosting per season increased by 148% (0.00058 to 0.00143) compared to pre-acquisition levels. More roosts, numbers of cranes roosting, and the proportion of the population roosting were observed after PRRIP acquisition of these areas while the number of seasons were fewer under PRRIP management. Across the 23 managed areas, we observed 75 cranes before PRRIP acquisition over 525 migration seasons totaled. After PRRIP acquisition, we observed 291 cranes over 441 migration seasons. After accounting for the number of survey seasons and population increase during our study period, 13 of 23 areas had increased proportional use per season by whooping cranes after PRRIP acquisition: Over all areas, we observed a statistically significant increase in the proportion of the whooping crane population roosting each season after PRRIP acquisition ($V=36$, $p = 0.011$).

At PRRIP managed areas in the western portion of the AHR, 171 cranes were observed after acquisition over a total of 289 survey seasons compared to 13 cranes over 257 survey seasons before PRRIP acquisition. Cottonwood Ranch had the highest number of roosting cranes in the western AHR after the Program began managing the property (57 cranes; proportion per season = 0.0041). Ten of 13 western areas had an increase in the proportion of the population roosting per season after PRRIP acquisition, resulting in a statistically significant increase in use after acquisition ($V=2$, $p = 0.007$).

At PRRIP managed areas in the eastern portion of the AHR, 120 cranes were observed after acquisition over a total of 152 survey seasons compared to 62 cranes over 268 survey seasons before PRRIP acquisition. Binfield had the greatest number of roosting cranes in the eastern AHR after acquisition (46 cranes; proportion per season = 0.0046). Only three of 13 eastern areas had an increase in the proportion of the population roosting per season after PRRIP acquisition, and the increase in proportional use per season after acquisition was not statistically significant (V=21, $p = 0.906$).

4 – DISCUSSION

Our 22-year assessment of whooping crane riverine roost site selection within the Program’s AHR on the central Platte River reinforced the importance of channel openness and clearing or maintaining riparian forest a minimum distance away from the channel as established by Howlin and Nasman (2017) and Baasch et al. (2019a). We also assessed the contribution of the surrounding landscape to riverine roosting patterns and identified development as a factor negatively influencing roost site selection. The proportion of other landcover types, such as grassland, meadow marsh, agricultural wetland, and corn surrounding roost locations had little influence on riverine roost site selection within the AHR. Interactions among variables were also unimportant for predicting roost site selection.

Our results demonstrate a robust, long-term pattern of whooping crane avoidance of roosting on river channels with forested areas closer than 550 ft. These results corroborate findings from past studies both outside and within the AHR. Austin and Richert's (2005) study of habitat use across the U.S. migratory corridor documented a lack of trees and shrubs near whooping crane roosts. Within the AHR, our current results found whooping crane selection of riverine habitat for roosting increased as distance to nearest forest increased up to 623 ft. The selection relationship demonstrated no additional benefit in terms of increased roosting predicted for maintaining forest at distances further away from the river. These findings are very similar to results of Howlin and Nasman (2017) and Baasch et al. (2019a). In the AHR, the availability of roosting habitat farther than 800 ft from forest is minimal due to woody encroachment throughout the historical floodplain, including river islands and along banks of the active river channel (Johnson 1994). As such, few roosts have occurred further than 800 ft from forest. It is also worth noting that nearest forest is measured in any single direction from in-channel roost locations. Since the PRRIP (2017b) and Baasch et al. (2019a) work was completed, the Program has managed for two times the 550 ft recommended distance to nearest forest to manage for at least an 1,100 ft unforested corridor width to allow for the same distance from forest on both sides of roost locations.

In addition to forest avoidance, we provide further evidence in support of whooping crane selection for wide river channels void of tall vegetation. Early observations of roost sites along the Platte River also identified avoidance of narrow channels or wide channels containing many vegetated sandbars (Lingle et al. 1984, Faanes et al. 1992, Austin and Richert 2005). However, the selection for unobstructed channel width (UOCW) in our updated analysis extended beyond the widths identified in recent studies. Prior investigations demonstrated selection of river channels increased as UOCW increased to a width of 488 ft (Howlin and Nasman 2017) and 689 ft (Baasch et al. 2019a) with no additional increase in selection as UOCW increased beyond those widths. After adding data from 2017-2022, we found the maximized selection ratio of UOCW was at 1,223 ft, but selection was statistically similar between the current management objective for the Program (650 ft) and 1,223 ft. This relationship may partly reflect limited availability of extremely wide channels in the dataset, where few roosts and available locations exceed 1,000 ft and limit our ability to assess selection at those widths. While additional extremely wide channels might allow for clearer inference, creating UOCWs >1,000 ft would require extensive intervention and cost. Moreover, maintaining this channel width would likely exceed the capacity of the current AHR flow regime and would necessitate frequent mechanical intervention to preserve channel openness.

Though the amount of development on the landscape contributes less to explaining roost site selection than in-channel metrics, we did find that whooping cranes avoid even small areas of development when selecting roost sites in the AHR. Whooping cranes have a well-established aversion to development or disturbance at both local and landscape scales. Whooping cranes have demonstrated avoidance of areas with high road density and other forms of human infrastructure on the landscape throughout the migratory corridor (Johns et al. 1997, Belaire et al. 2014, Niemuth et al. 2018, Pearse et al. 2021). Within the AHR, Howlin and Nasman (2017) and Baasch et al. (2019b) found whooping cranes avoid areas near development for roosting and diurnal habitat selection, respectively. Baasch et al. (2022) found development within 0.62 miles impacted patterns of off-channel diurnal use for whooping cranes in the AHR. The Program could use the relationship between development and roost site selection established in the current study to consider how nearby development may impact suitability when assessing land for habitat acquisition.

Contribution of channel management to roosting conditions

Increases in unobstructed channel width (UOCW) at whooping crane roost locations reflect the combined effects of natural peak flow events in 2015 and 2019 and mechanical management actions such as disking and in-channel vegetation removal. Across the AHR, high flows during the 2015-2022 period contributed to wider channels regardless of ownership or management status, as seen in the increasing UOCW values in both managed and unmanaged areas—especially in the eastern AHR. However, in the western AHR, the most pronounced gains in UOCW occurred in managed areas, suggesting that management can play an important role in maintaining habitat created through natural peak flows.

While trends in nearest forest (NF) were less consistent and smaller over time, greater distances to forest were ultimately observed at roosts in managed areas compared to areas not managed to provide habitat for whooping cranes across the AHR after 2014. Gains on PRRIP managed properties were in part due to PRRIPs management objective and practicality of implementation. PRRIP's management objective of maintaining an unforested corridor width of 1,100 ft was based upon doubling the 550 ft distance to NF, found by Baasch et al. (2019), to be an important selection criterion (Baasch et al. 2019), to allow whooping cranes to roost in the channel while keeping this distance from trees on either bank. With limited increases in whooping crane roosting predicted if forest were removed past 550 ft, once the 1,100 ft unforested corridor was achieved the Program did not remove more trees. In the western AHR, achieving this corridor width often required more tree removal, contributing to the increase in NF values and greater roost use of managed areas in this reach. In the eastern AHR, early conservation efforts by PRRIP partners contributed to wider NF conditions that have been maintained by the Program and its partners.

Overall, PRRIP's greatest contribution to roosting conditions appears to be in the western half of the AHR where increased use of wider channel conditions (both UOCW and NF) mainly occurred on Program managed properties from 2015-2022. The Program focused early land acquisition on the western half of the reach and followed up with mechanical efforts to increase the distribution of suitable whooping crane habitat across the AHR. Our current assessment of PRRIP's contribution to whooping crane roosting habitat based upon characteristics of first unique roosts over time, space, and management is largely qualitative. However, it does provide a look at how characteristics at roost sites have changed and introduces future work to quantify and assess the relative contributions of base flows, germination suppression flows and the various mechanical management actions implemented by the Program and partners to maintain and improve UOCW and NF conditions used by roosting whooping cranes throughout the AHR.

PRRIP Contribution to WC Roosting

Our analysis indicated that PRRIP-managed lands have supported increased whooping crane use over time, both in terms of the number of cranes and the proportion of the Aransas–Wood Buffalo population utilizing these areas each season. By standardizing crane observations by seasonal population estimates and normalizing across unequal numbers of migration seasons, we were able to isolate the effect of PRRIP habitat management from confounding factors such as overall population growth and differences in numbers of seasons each property was managed by PRRIP. In doing so, we found a significant increase in proportional use of properties across the AHR following PRRIP management as well as significant increases when only sites west of Kearney were examined. Increases in the west, but not in the east, were likely due to pre-existing differences in roosting conditions west of Kearney versus east of Kearney at the inception of the Program. Crane habitat in the western AHR was considered degraded in 2007, with fewer conservation efforts to improve channel conditions for whooping crane roosting than in the eastern AHR. After Program management, many western areas experienced dramatic improvements in roosting conditions compared to pre-acquisition, likely why many areas saw increased crane use. In the eastern AHR, many areas acquired by PRRIP were already in conservation ownership, so better roosting conditions for whooping cranes were already present prior to Program acquisition with fewer actions needed to bring areas to the Program's suitable habitat standard for whooping cranes.

5 – PROGRAM MANAGEMENT IMPLICATIONS

The Program's definition of highly suitable whooping crane roosting habitat has not changed because of the Program's five-year check-in on learning about the factors that influence whooping crane roost site selection. Like previous analyses, NF and UOCW remain important for Program management of on-channel whooping crane roosting habitat. The Program will continue to manage on-channel habitat complexes to create or maintain unforested corridor widths of at least 1,100 ft (two times the 550 ft recommended distance to nearest forest) to allow for the same distance from forest on both sides of roost locations. Given the statistical similarity of whooping crane roost site selection for unobstructed channel widths ≥650 ft, the TAC did not make a recommendation to change the Program's current criteria for highly suitable roosting habitat of UOCW ≥650 ft.

Instead, the TAC asked the EDO to review the range of UOCWs at Program habitat complexes and identify locations where unobstructed widths are 1) narrower than can be maintained by base flows,2) UOCW could potentially be increased through low-cost management actions like disking and/or spraying of banks to promote lateral erosion and incremental gains in UOCW and 3) were narrower than 650 ft. To identify areas meeting these criteria, the EDO quantified the general relationship between flow consolidation at 1,500 cfs and UOCW throughout the AHR, which was chosen as a flow limit that the Program can generate with controllable water from the Environmental Account. For example, UOCW in fully consolidated channels was on the order of 1,000 ft. Channels conveying less than 50% of the flow (at 1,500 cfs) generally had UOCWs below 400 ft. This relationship was used to estimate the UOCW that could potentially be maintained by river flow (width potential) without the need for constant mechanical intervention in the future.

The EDO and TAC then compared existing channel widths along standardized transects at 1,000 ft intervals throughout each habitat complex to estimated width potential to identify locations that could be widened. Portions of the Cottonwood Ranch complex (between Overton and Elm Creek river bridges) and the Jerry F. Kenny Pawnee Complex (between Odessa and Kearney river bridges) had channels that were narrower than width potential. Moving forward, annual work plans for those complexes will formally incorporate targeted mechanical/chemical management actions to encourage channel widening until channels reach widths maintainable by river flows.

As the only off-channel element of the surrounding landscape to influence whooping crane roost site selection in the current analysis, the amount of development surrounding on-channel habitat should also be considered when assessing land for whooping crane habitat suitability. Though other landcover types were explored for their influence on whooping crane roost site selection, they had little influence on selection of riverine roost sites. This result supports the Program’s current management focus on creating and maintaining wide, unobstructed in-channel roosting habitat.

6 – LITERATURE CITED

Arnold, T. W. 2010. Uninformative Parameters and Model Selection Using Akaike's Information Criterion. The Journal of Wildlife Management 74:1175–1178.

Arthur, S. M., B. F. J. Manly, L. L. McDonald, and G. W. Garner. 1996. Assessing Habitat Selection when Availability Changes. Ecology 77:215–227.

Austin, J., and A. Richert. 2005. Patterns of habitat use by whooping cranes during migration: summary from 1977-1999 site evaluation data. Proceedings of the North American Crane Workshop. <https://digitalcommons.unl.edu/nacwgproc/8>.

Baasch, D. M., A. J. Caven, J. G. Jorgensen, R. Grosse, M. Rabbe, D. M. Varner, and T. LaGrange. 2022. Whooping Crane (Grus americana) use patterns in relation to an ecotope classification in the Central Platte River Valley, Nebraska, USA. Avian Conservation and Ecology 17. <http://www.ace-eco.org/vol17/iss2/art35/>.

Baasch, D. M., P. D. Farrell, S. Howlin, A. T. Pearse, J. M. Farnsworth, and C. B. Smith. 2019a. Whooping crane use of riverine stopover sites. C. R. Brown, editor. PLOS ONE 14:e0209612.

Baasch, D. M., P. D. Farrell, A. T. Pearse, D. A. Brandt, A. J. Caven, M. J. Harner, G. D. Wright, and K. L. Metzger. 2019b. Diurnal habitat selection of migrating Whooping Crane in the Great Plains. Avian Conservation and Ecology 14:art6.

Belaire, J., B. J. Kreakie, T. Keitt, and E. Minor. 2014. Predicting and mapping potential whooping crane stopover habitat to guide site selection for wind energy projects. Conservation biology 28:541–550.

Boryan, C., Z. Yang, R. Mueller, and M. Craig. 2011. Monitoring US agriculture: the US

Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program. Geocarto International 26:341–358.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Brei, J., and A. Bishop. 2008. Platte River vegetation mapping project 2005 land cover methods summary. Platte River recovery implementation program report, Kearney, Nebraska, USA. https://www.rwbjv.org/wp-content/uploads/Platte-River-2005-Land-Cover-Methods.pdf

Breiman, L. 2001. Random Forests. Machine Learning 45:5–32.

Brunner, G. W. 1996. HEC-RAS (River Analysis System). Pages 3782–3787 in. ASCE. https://cedb.asce.org/CEDBsearch/record.jsp?dockey=0100264

Burnham K. P. and D. R. Anderson. 2002. Model selection and multimodel inference, 2nd Ed. Springer, New York, New York, USA.

Canadian Wildlife Service and U.S. Fish and Wildlife Service (CWS and USFWS). 2007. International recovery plan for the whooping crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.

Caven, A. J., A. T. Pearse, D. A. Brandt, M. J. Harner, G. D. Wright, D. M. Baasch, E. M. Brinley Buckley, K. L. Metzer, M. R. Rabbe, and A. E. Lacy. 2022. Whooping Crane Stay Length in Relation to Stopover Site Characteristics. Proceedings of the North American Crane Workshop.

Faanes, CA. Unobstructed visibility at whooping crane roost sites on the Platte River, Nebraska.

Pages 117–120in Wood DA,ed. 1992. Proceedings 1988 North American Crane Workshop, Feb.22–24, 1988. Lake Wales, Florida.

Fotherby, L. M. 2009. Valley confinement as a factor of braided river pattern for the Platte River. Geomorphology 103:562–576.

Han, W., Z. Yang, L. Di, and R. Mueller. 2012. CropScape: A Web service based application for exploring and disseminating US conterminous geospatial cropland data products for decision support. Computers and Electronics in Agriculture 84:111–123.

Hastie, T. J., and R. J. Tibshirani. 1990. Generalized additive models. Volume 43. CRC Press.

Howlin, S., W. P. Erickson, and R. M. Nielson. 2003. A validation technique for assessing predictive abilities of resource selection functions. Pages 40–51 in. Proceedings of the first international conference on resource selection. Laramie, Wyoming.

Howlin, S., and K. Nasman. 2017. Correlates of whooping crane habitat selection and trends in use in the central Platte River, Nebraska. Western EcoSystems Technology, Inc. https://platteriverprogram.org/sites/default/files/PubsAndData/ProgramLibrary/Correlates%20of%20Whooping%20Crane%20Habitat%20Selection%20and%20Trends%20in%20Use%20in%20the%20Central%20Platte%20River.pdf

Johns, B., E. Woodsworth, and E. Driver. 1997. Habitat use by migrant whooping cranes in Saskatchewan. Proceedings of the North American Crane Workshop.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61:65–71.

Johnson, W. C. 1994. Woodland Expansions in the Platte River, Nebraska: Patterns and Causes. Ecological Monographs 64:45–84.

Kuyt, E. 1992. Aerial radio-tracking of whooping cranes migrating between Wood Buffalo

National Park and Aransas National Wildlife Refuge, 1981-84. 74, Canadian Wildlife Service.

Lennon, J. J. 1999. Resource selection functions: taking space seriously? Trends in Ecology & Evolution 14:399–400.

Lingle G R, P J Currier, K L Lingle. Physical characteristics of a whooping crane roost site on the Platte River, Hall County, Nebraska. Prairie Nat. 1984; 16: 39–44.

Manly, B. F. L., L. McDonald, D. Thomas, T. L. McDonald, and W. P. Erickson. 2007. Resource selection by animals: statistical design and analysis for field studies. Springer Science & Business Media.

McCracken, M. L., B. F. J. Manly, and M. V. Heyden. 1998. The Use of Discrete-Choice Models for Evaluating Resource Selection. Journal of Agricultural, Biological, and Environmental Statistics 3:268–279.

Murphy, P.J., Randle, T.J., Fotherby, L.M. and Daraio, J.A., 2004. Platte River channel: history and restoration. Denver, Colorado: US Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, CO.

Niemuth, N. D., A. J. Ryba, A. T. Pearse, S. M. Kvas, D. A. Brandt, B. Wangler, J. E. Austin, and M. J. Carlisle. 2018. Opportunistically collected data reveal habitat selection by migrating Whooping Cranes in the U.S. Northern Plains. The Condor 120:343–356.

O'Brien, J.S. and Currier, P.J., 1987. Channel morphology and riparian vegetation changes in the Big Bend Reach of the Platte River in Nebraska. Platte River Whooping Crane Habitat Maintenance Trust (Unpublished Report).

Pearse, A. T., D. A. Brandt, W. C. Harrell, K. L. Metzger, D. M. Baasch, and T. J. Hefley. 2015. Whooping crane stopover site use intensity within the Great Plains. Open-File Report, USGS Numbered Series, U.S. Geological Survey, Reston, VA.

Pearse, A. T., M. J. Harner, D. M. Baasch, G. D. Wright, A. J. Caven, and K. L. Metzger. 2017. Evaluation of nocturnal roost and diurnal sites used by whooping cranes in the Great Plains, United States. Evaluation of nocturnal roost and diurnal sites used by whooping cranes in the Great Plains, United States. Volume 2016–1209. Open-File Report, USGS Numbered Series, U.S. Geological Survey, Reston, VA.

Pearse, A. T., M. Rabbe, L. M. Juliusson, M. T. Bidwell, L. Craig-Moore, D. A. Brandt, and W. Harrell. 2018. Delineating and identifying long-term changes in the whooping crane (*Grus americana*) migration corridor. PLOS ONE 13:e0192737.

Pearse, A. T., K. L. Metzger, D. A. Brandt, M. T. Bidwell, M. J. Harner, D. M. Baasch, and W. Harrell. 2020a. Heterogeneity in migration strategies of Whooping Cranes. The Condor 122.

Pearse, A. T., Brandt, D. A., Baasch, D. M., Bidwell, M. T., Conkin, J. A., Harner, M. J., Harrell, W., & Metzger, K. L. 2020b. Location data for whooping cranes of the Aransas-Wood Buffalo Population, 2009-2018 [Data set]. U.S. Geological Survey. https://doi.org/10.5066/P9Y8KZJ9

Pearse, A. T., K. L. Metzger, D. A. Brandt, J. A. Shaffer, M. T. Bidwell, and W. Harrell. 2021. Migrating Whooping Cranes avoid wind-energy infrastructure when selecting stopover habitat. Ecological Applications 31:e02324.

Platte River Endangered Species Partnership. 2001a. Monitoring Whooping Crane Migrational Habitat Use in the Central Platte River Valley. February 23, 2001.

Platte River Endangered Species Partnership. 2001b. Monitoring Whooping Crane Migrational Habitat Use in the Central Platte River Valley. September 12, 2001.

Platte River Endangered Species Partnership. 2001c. Monitoring Whooping Crane Migrational Habitat Use in the Central Platte River Valley. December 20, 2001.

Platte River Endangered Species Partnership. 2002. Monitoring Whooping Crane Migrational Habitat Use in the Central Platte River Valley. August 1, 2002.

Platte River Endangered Species Partnership. 2003. Draft Monitoring Whooping Crane Migrational Habitat Use in the Central Platte River Valley. August 21, 2003.

Platte River Recovery Implementation Program (PRRIP). 2017a. Adjustments to the WC Monitoring Protocol. https://platteriverprogram.org/sites/default/files/PubsAndData/ProgramLibrary/PRRIP%20Adjustments%20to%20Whooping%20Crane%20Monitoring%20Protocol%2C%202001-2017.pdf

Platte River Recovery Implementation Program (PRRIP). 2017b. Platte River Recovery Implementation Program Data Synthesis Compilation Whooping Crane (*Grus americanus*) Habitat Synthesis Chapters. https://platteriverprogram.org/sites/default/files/PubsAndData/ProgramLibrary/PRRIP%20Whooping%20Crane%20Habitat%20Synthesis%20Chapters.pdf

Platte River Recovery Implementation Program (PRRIP). 2017c. Whooping Crane Monitoring Protocol – Migrational Habitat Use in the Central Platte River Valley. https://platteriverprogram.org/sites/default/files/PubsAndData/ProgramLibrary/PRRIP%2

0Whooping%20Crane%20Monitoring%20Protocol%20–%20Migrational%20Habitat%20Use%20in%20the%20Central%20Platte%20River%20Valley-2017.pdf

Platte River Recovery Implementation Program (PRRIP). 2020. 2019 State of the Platte – Adaptive Management Plan (AMP) 2019 "Big Question" Assessments February 20, 2020. pp. 13. https://platteriverprogram.org/sites/default/files/2020-08/FINAL%202019%20PRRIP%20State%20of%20the%20Platte.pdf

Platte River Recovery Implementation Program (PRRIP). 2021a. Final Platte River Recovery Implementation Program Cooperative Agreement, Attachment 3 – Adaptive Management Plan. p. 72. https://platteriverprogram.org/sites/default/files/2021-09/PRRIP%20Full%20Program%20Document%20Updated%209_14_2021.pdf

Platte River Recovery Implementation Program (PRRIP) 2022a. First Increment Extension Science Plan. https://platteriverprogram.org/document/prrip-extension-science-plan

Platte River Recovery Implementation Program (PRRIP). 2022b. System-Scale Geomorphology and Vegetation Monitoring Report 2017-2020. https://platteriverprogram.org/document/system-scale-geomorphology-and-vegetation-monitoring-report-2017-2020

Platte River Recovery Implementation Program (PRRIP). 2023. System-Scale Geomorphology and Vegetation 2023 Update. https://platteriverprogram.org/system/files/2023-10/06%20-%20System%20Geomorph%20Update_1.pdfPosit Team (2023). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. http://www.posit.co/.

R Core Team (2023). R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Shenk, T. M., and M. J. Armbruster. 1986. Whooping crane habitat criteria for the Big Bend area of the Platte River. Unpublished report to Biological Ad Hoc Workshop, Platte River Management Joint Study. US Fish and Wildlife Service, National Ecological Research Center, Fort Collins, Colorado, USA.

United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS). 2019. Web Soil Survey. Soil Survey Division. http://websoilsurvey.nrcs.usda.gov/

United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS). 2020. Soil Survey Geographic (SSURGO) Database. https://sdmdataaccess.sc.egov.usda.gov/Query.aspx

United States Fish and Wildlife Service (USFWS). 1978. Determination of critical habitat for the Whooping Crane. *Federal Register* 43.94: 20938-20942.

United States Fish and Wildlife Service (USFWS). 2021. National Wetlands Inventory website. Website. U.S. Fish and Wildlife Service, Washington, D.C., USA. http://www.fws.gov/wetlands

Wood, S. 2006. Generalized additive models: an introduction with R. CRC press.

7 – APPENDICES

Appendix 1. ArcGIS Online (ESRI, 2025) providing examples of 2010 and 2022 annual landcover layers. Due to file size, additional annual landcover layers can be made available upon request. Roost/available locations utilized in current analysis (https://hwcorp.maps.arcgis.com/apps/instant/basic/index.html?appid=eb78754aa4c646609a9565320a2c8d5c).

Appendix 2. Model selection table to compare primary explanatory variables to alternative variables. Prior to development of our suite of models, we compared related primary and alternative variables to identify which measure of agriculture, forest, and development had the best explanatory power to describe patterns of roost site selection for whooping cranes. Comparisons were made using the Akaike Information Criterion (AIC) scores of single variable models. For agriculture, we compared the proportion of corn (CO) within 0.77 miles to the proportion of alfalfa (AL), proportion of soybeans (SO), and proportion of all other agriculture (OA) within 0.77 miles around roosts and available point locations. For forest, we compared the nearest forest (NF) to unforested channel width (UFCW) at roosts and available locations and the proportion of forest (FO) within 0.77 miles. For development, we compared the proportion of development (DE) within 0.77 miles around roosts and available point locations to the minimum distance from transmission lines (TL; Homeland Infrastructure Foundation-Level Data – U.S. Electric Power Transmission Lines) for each location. We chose to proceed with CO for the final suite of models despite CO having a greater ΔAIC than AL and OA due to the *a-priori* hypothesis of corn's importance to whooping crane use patterns in the Associated Habitat Reach.

Category	Variable	df	AIC	ΔAIC	Weight
Forest	NF	165.64	2824.98	0.00	1.00
Forest	UFCW	165.36	2898.05	73.07	0.00
Development	DE	163.00	2912.78	87.80	0.00
Forest	FO	165.83	2922.13	97.15	0.00
Development	TL	163.00	2955.19	130.21	0.00
Agriculture	AL	164.87	2958.54	133.57	0.00
Agriculture	OA	163.00	2960.69	135.72	0.00
Agriculture	CO	163.00	2962.11	137.13	0.00
Agriculture	SO	163.00	2962.36	137.39	0.00